WATER-SENSITIVE URBAN DESIGN AND PLANNING

A Practitioner's Guide

Centre for Science and Environment
Ministry of Housing and Urban Affairs

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Research director and coordinator: Suresh Kumar Rohilla

Writers: Mahreen Matto, Shivali Jainer and Chhavi Sharda

Editor: Archana Shankar

Design and cover: Kirpal Singh

Production: Rakesh Shrivastava and Gundhar Das

We are grateful to the Ministry of Housing and Urban Affairs, Government of India, for their support to CSE as a Centre of Excellence for Sustainable Water Management.

ISBN: 978-81-86906-17-0

Price: ₹220 (US $14)

Citation: Suresh Kumar Rohilla, Mahreen Matto, Shivali Jainer and Chhavi Sharda 2017, *Water-Sensitive Urban Design and Planning: A Practitioner's Guide*, Centre for Science and Environment, New Delhi

Published by
Centre for Science and Environment
41, Tughlakabad Institutional Area, New Delhi 110 062
Phones: 91-11-40616000
Fax: 91-11-29955879
E-mail: cse@cseindia.org
Website: www.cseindia.org

Printed at Bravo Printex, New Delhi

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Abbreviations

BMP	Best management practices
CIRIA	Construction Industry Research and Information Association
CN	Curve number
CoE	Centre of Excellence
CPHEEO	Central Public Health and Environmental Engineering Organisation
DDA	Delhi Development Authority
DPR	Detailed project report
DWWTs	Decentralized wastewater treatment system
EIA	Environment Impact Assessment
GI	Galvanized iron
LID	Low impact development
MoHUA	Ministry of Housing and Urban Affairs
NGO	Non-governmental organization
PVC	Polyvinyl chloride
RCC	Reinforced cement concrete
RWA	Residents Welfare Association
RWH	Rainwater harvesting
STP	Sewage treatment plant
SUDS	Sustainable urban drainage system
ULB	Urban local bodies
URDPFI	Urban and Regional Development Plans Formulation & Implementation
USEPA	United States Environmental Protection Agency
WSUDP	Water-sensitive urban design and planning

Glossary

Aerobic	A state requiring or allowing the presence of free essential oxygen.
Anaerobic	The absence of free elemental oxygen, the state of not requiring or damage by the absence of free elemental oxygen.
Aquifer	A porous, water-logged sub-surface geological formation. The description is generally restricted to media capable of yielding a substantial supply of water.
Bio-retention area	A depressed landscape that collects storm-water runoff that infiltrates into the soil below through the root zone, prompting pollutant removal.
Buffer strip	A vegetated area ordinarily situated on gently sloping ground designed to filter out insoluble pollutants in runoff. It is also known as filter strip.
Contamination	The introduction of microorganisms, factory-produced chemicals or wastewater in concentrations that render water unsuitable for most uses.
Detention pond	A pond that is normally dry except following large-storm events when it temporarily stores storm water to attenuate flows. It may also allow infiltration of storm water into the ground.
Filtration	Also referred to as bio-filtration, the filtering out of storm-water runoff pollutants conveyed with sediment by trapping them on vegetative species in the soil matrix or on geo-textiles.
Flood	A temporary rise in water level, including groundwater or overflow of water, onto land not normally covered by water.
Green roof	A roof on which plants and vegetation can grow. The vegetated surface provides a degree of retention, attenuation, temperature insulation and treatment of rainwater.
Infiltration	The process of penetration of rainwater into the ground.
Rainwater harvesting	The direct capture of storm-water runoff, typically from rooftops, for supplementary water uses on-site.
Runoff	The excess water that flows after precipitation.
Storm water	Water resulting from natural precipitation and/or accumulation. It includes rainwater, groundwater and spring water.
Watershed	The upper boundary of a specified catchment area for rainfall that contributes to a given drainage area.
Wetland	Land inundated or saturated by surface- or groundwater at a frequency and duration sufficient to support, and under normal circumstances does support, vegetation (hydrophytes) typically adapted for life in saturated soil conditions (hydric soils).

Executive summary

Water-sensitive urban design and planning (WSUDP) integrates the urban water cycle, water supply, wastewater, storm-water and groundwater management with spatial and urban design. This approach contributes to sustainability and livability, particularly when considered part of an overall urban strategy.

This guide to WSUDP aims to assist practitioners involved in sectors related to water management as well as urban designing and planning. Its purpose is to explore possible innovations spanning areas of alternative approach of water management and show how it can be applied in cities while taking up existing opportunities to use it for increasing cities' amenities and quality of life. It also describes how to develop a specific WSUDP strategy for a new development as per site conditions.

For upcoming development, appropriate methods and strategies under WSUDP are provided according to the scale of urban planning, i.e. city/zonal, neighbourhood/institutional and individual scale. Water-sensitive planning principles are showcased first according to different land uses and water-intensive activities in cities/zones. The focus moves to water-sensitive urban designs and then individual-level designs.

Overall social, economic and environmental impacts of WSUDP are also discussed in this guide. The application of water-sensitive practices, with economic analyses and feasibility according to the respective land uses, are highlighted. The importance of operation and maintenance, along with stakeholder involvement which provides the base for implementation of WSUDP measures, is also discussed.

The approach of this guide is aligned with the 2030 Sustainable Development Goals, which include clean water, sanitation and sustainable cities, with community involvement, as major priorities. It is supported by international best management practices along with feasibility studies for WSUDP in India.

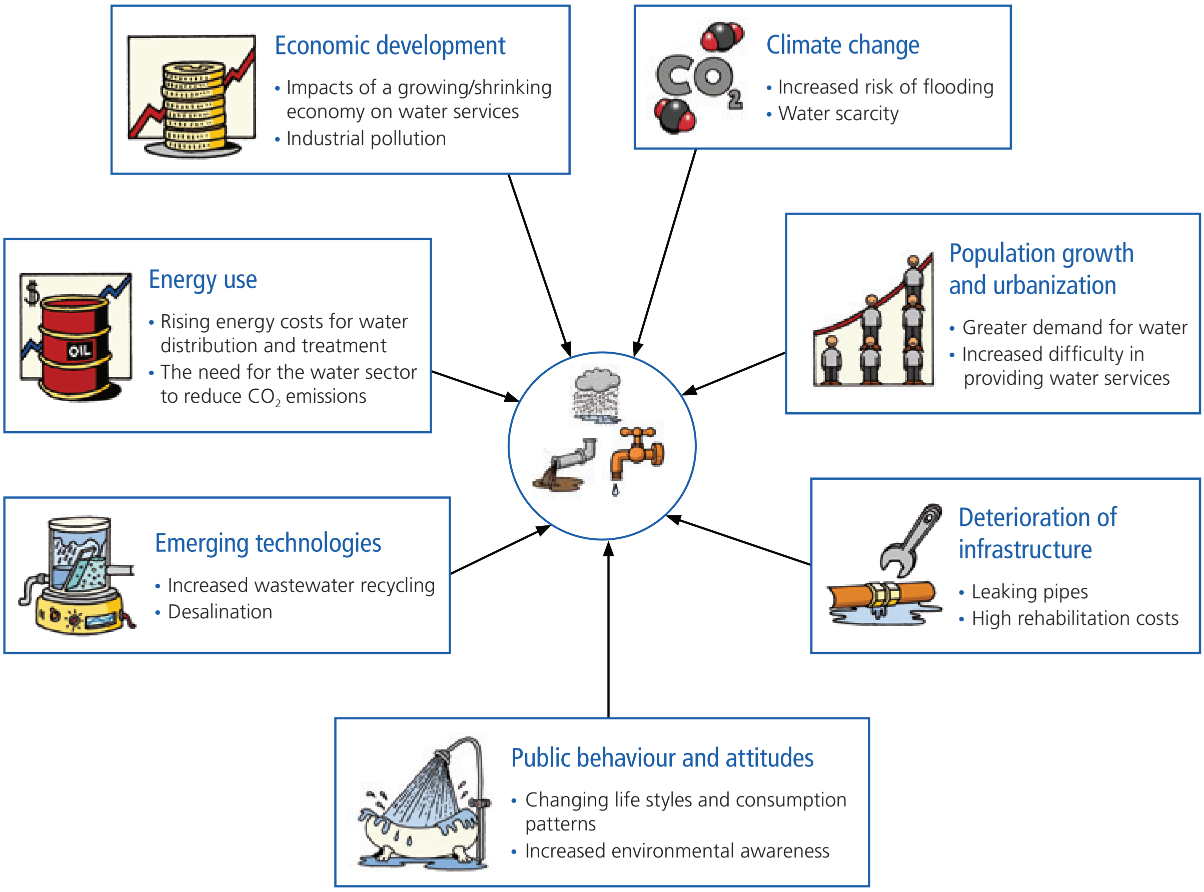
It intends to assist practitioners manage available local water resources in a sustainable way by integrating it into the planning and designing of cities.

1. Introduction

1.1 Background

Urban water systems are confronted with significantly changing conditions. The impacts of climate change, rapid urbanization, and deteriorating and outdated infrastructure aggravate current water challenges of causing flooding, water scarcity and rehabilitation costs on a scale that will overwhelm the capacities of cities (see *Figure 1: Development challenges for water management in cities*).[1]

Figure 1: Development challenges for water management in cities

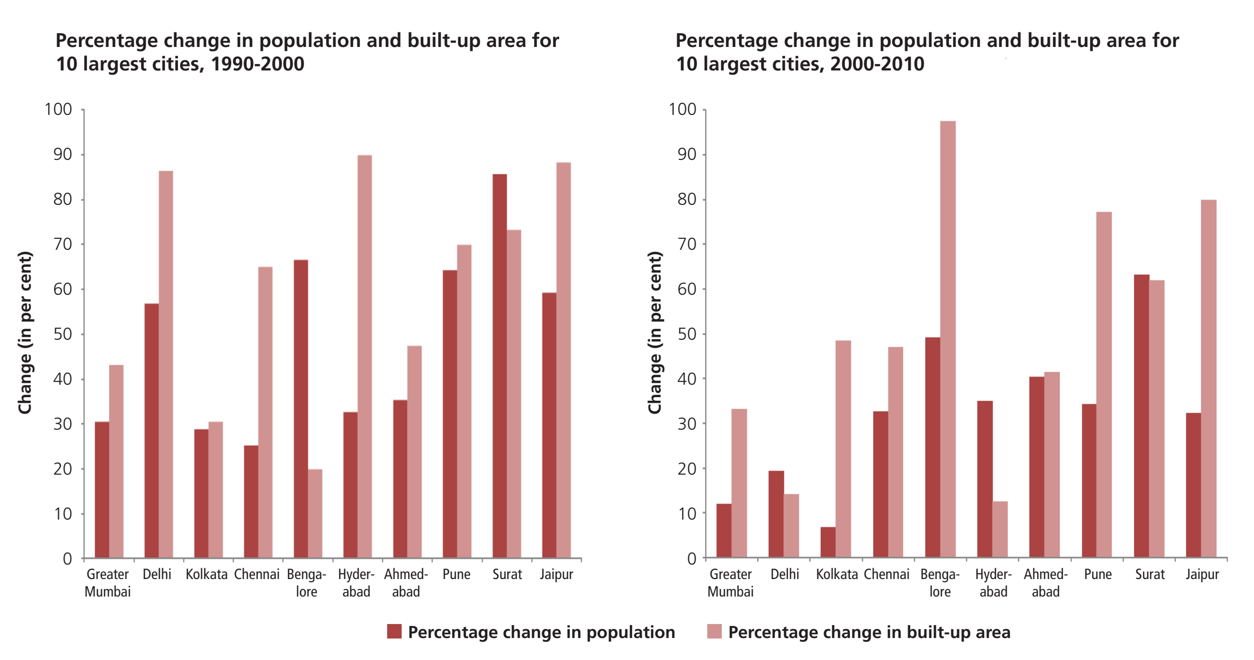


Source: SWITCH Training Kit (2011) Integrated Urban Water Management in the City of the Future. Module 1—Strategic Planning: Preparing for the Future.

The World Resource Institute global water-stress rankings (2013) indicate that the ratio of withdrawal to supply in India is 40 to 80 per cent and the country experiences high water stress.[2] India has witnessed a rapid increase in the urban population during the last few decades. All towns and cities currently face the problem of increasing gap between water supply and demand, which puts pressure on water resources and its supply requirements.

By 2030, India will have 68 cities with populations of over 1 million. Growing urban centres, with the concurrent process of urbanization, have brought several issues to the fore, from governance and management of these areas to

Figure 2: Urbanization and increase in built-up area, India



Source: Indian Institute for Human Settlements. 2012. Urban India 2011: Evidence.

the provision of basic civic services. Consequently, there is heavy pressure on water management.[3]

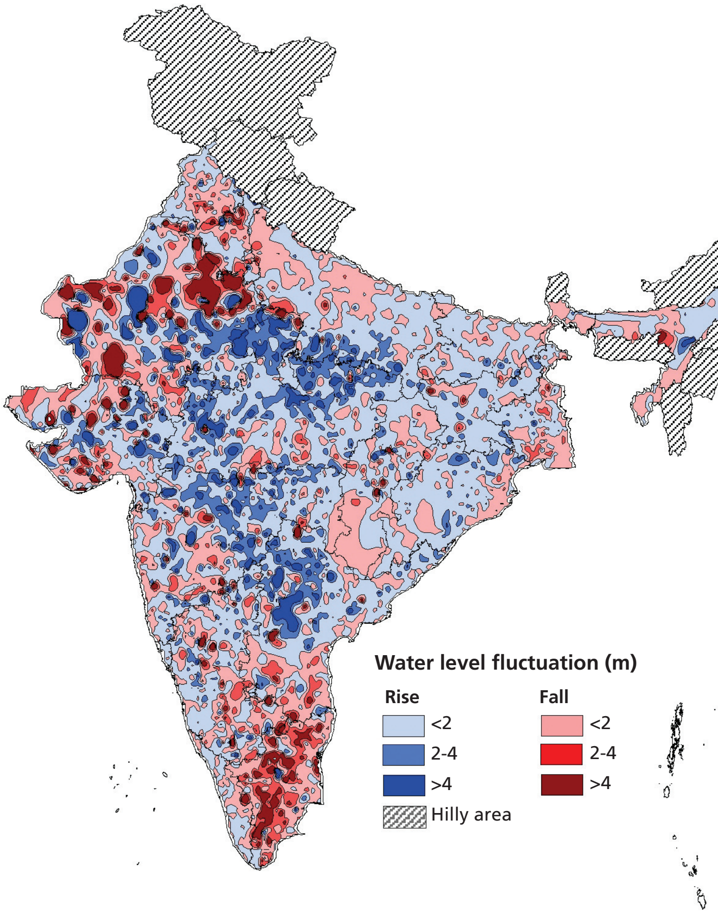
In the last two decades, built-up area has grown faster than population in nearly all of India's largest cities. A comparison shows that the spatial expansion has accelerated between 2000 and 2010 (see *Figure 2: Urbanization and increase in built-up area, India)*.

Water supply in most Indian cities refers to the layout of infrastructure, i.e. piped water-supply lines, sewage lines, sewage treatment plants (STPs) and layout of drainage lines. If the piped water supply is inadequate, it is supplemented by private uncontrolled groundwater extraction, which contributes to pollution of urban aquifers and fall in groundwater levels. People either dig wells and tube wells on their properties for their water needs or buy water from private tankers that, in turn, extract groundwater for sale (see *Map 1: Decadal fluctuation in groundwater levels [2004–13])*.[4]

Water sources are also highly polluted, limited and subsidized for domestic consumption. No fixed or standard pricing exists for groundwater extraction. According to a Centre for Science and Environment (CSE) study, the water price charged to consumers in metro cities such as Delhi and Bengaluru is Rs 0.35 per 1,000 litres and Rs 5 per 1,000 litres respectively, which is fairly low as compared to actual cost of water supply, i.e. Rs 72 per 1,000 litres and Rs 93 per 1,000 litres, respectively. This leads to increased consumption and wasteful utilization of water in the country.[4]

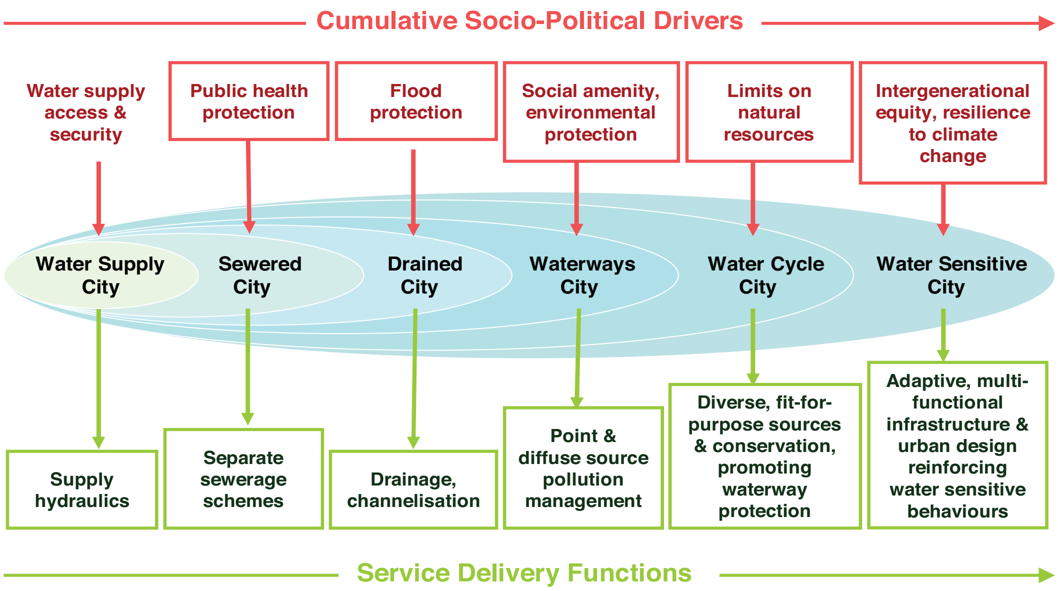
Around 40–90 per cent of the total water consumption goes out as wastewater.[5] A CSE survey indicates that there is a complete disconnect between water supply and sewage management in India.[6] Only 30 per cent of sewage from Indian cities is treated at STPs. The remainder pollutes natural waterbodies.

Map 1: Decadal fluctuation in groundwater levels (2004–13)



Source: State of India's Environment, 2016. *Down To Earth*, Centre for Science and Environment.

Figure 3: Urban water management transition framework



Source: Brown, R., Keath, N. and Wong, T., 2008, August. Transitioning to Water Sensitive Cities: Historical, Current and Future Transition States. In 11th International Conference on Urban Drainage (Vol. 10).

The increasing demand–supply gap and deteriorating environmental conditions are increasing the need for environmentally friendly alternatives. It is important to take up the challenge in controlling and judiciously using natural resources to reduce our ecological footprint. Sustainable water management requires a holistic approach toward sustainability along with prudent use of water resources.[7] *Figure 3: Urban water management transition framework* shows the transition in planning and designing of cities and their water management.

1.2 Need for a guide

It is clear from the existing situation that a re-focussing of priorities is required by way of careful planning to have sustainable water management.[9]

Adopting water sensitivity at the stage of planning and designing new and existing developments can maintain the water cycle by managing the supply and demand for water, storm water, wastewater and groundwater as well as bring benefits such as reduction in temperature with respect to climate change and adaptation.[9] The current policies, plans and guidelines in India that address water and the status of potential WSUDP interventions in these legislative frameworks to attain a sustainable water management is given in detail (see *Appendix A*).

This guide provides a solution to overcome water management issues that arise from increasing urbanization. It gives information to identify the potential and implement WSUDP within the existing framework of policies, guidelines, planning standards and building bylaws.

The objectives of the guide are to:

1. Sensitize practitioners about the need for and concept of WSUDP
2. Provide inputs on WSUDP with regard to planning and designing on different scales
3. Present case studies in support of WSUDP principles and analyse relevant tools and techniques

How to use the guide

This guide shows users and implementers the possibilities and benefits from engaging with water issues in an integrated way through partnerships with the agencies involved in water management. It signposts a wide range of other guidance and useful sources and presents numerous examples of good practice to show what is possible across the spectrum of water issues.

> This practitioner's guide provides an opportunity to incorporate water sensitivity into the planning and design of new and existing developments at the city, neighbourhood and individual levels.
>
> It also integrates best management practices (BMPs) related to water management at the strategic level of planning and design to achieve environmental, economic and social balance. Thus the guide can integrate with the existing plans/guidelines so as to have an affordable system of sustainable water management.

Target group

The target audience for this guide comprises city officials from urban local bodies (ULBs) and development authorities from states, such as urban planners, architects and landscape architects, town planning officers, engineers, and others involved in preparing and enforcing regional and master plans, zonal plans, city development plans and city sanitation plans and other local design standards. It can be incorporated in the course module of various technical courses recognized by the Central Public Health and Environmental Engineering Organisation (CPHEEO), Ministry of Housing and Urban Affairs (MoHUA). Further non-state actors such as decision makers and technical staff from private organizations and resident welfare associations (RWAs) can also benefit from these suggestions.

Table 1: Recommended target users, based on the involvement in the formulation and evaluation of WSUDP strategies, provides an overview of the major user groups. It is assumed that the reader is familiar with the process of land development, planning framework for land rezoning and development approval processes in their local area.

(a) **Primary users:** Primary users have a direct influence on the process of WSUDP, which includes mainly government officials. This guide will help primary users identify issues that need to be addressed while formulating a WSUDP project and help them to come up with the appropriate/potential WSUDP approach at city/neighbourhood/individual level. Teachers and students of Public Health Engineering/Environmental Engineering can also benefit by adding WSUDP in their course curriculum.

(b) **Secondary users:** Secondary users may not directly have an impact on WSUDP projects but can capacitate or influence decision makers. Examples include NGOs and consultants.

Table 1: Recommended target users

Primary users	
Government bodies	**Target group**
• Development authorities • State urban development agencies • Town and country planning organization	• Urban planners: Chief town planner, senior town planner, junior town assistant planner
• Municipal corporation • Municipalities • Other urban local bodies	• Engineers: Superintending engineer, executive engineer, assistant engineer, environment engineer, project officer
• Public health engineering departments • Water supply and sewerage boards • Urban shelter improvement boards	• Engineers
Engineering colleges and institutes under the following courses	• Students and teachers: BE, B. Tech (Civil)/Environmental, i.e. future engineers in this sector
Post-graduate course in Public Health Engineering/ Environmental Engineering, short-term courses in Public Health Engineering/Environmental Engineering and refresher courses on various aspects of WSUDP	
Private organizations	Technical staff and decision makers
Consultants (EIA) Private organizations CBOs: RWA, residents	
Secondary users	
Non-governmental organizations and decision makers working in the water sector	

Source: CSE, 2016

Table 2: Objectives of the guide

Objectives	Main chapters	Content/sub-chapters
Objective 1	**Introduction to guide**	• Water stress level of India • Need for practitioner's guide • Target group for this guide • How to use the practitioner's guide
	Concept of WSUDP	• What is WSUDP? • Evolving international knowledge • Evolving Indian knowledge • Scope of WSUDP interventions in Indian cities
Objective 2	**WSUDP approach at different scales**	• Planning intervention and tools • Zonal/city level • Neighbourhood/sub-city • Individual level—campus/institutions • Integration of different WSUDP measures
	Implementation of WSUDP concept	• Operation and maintenance • Stakeholder analysis • Economic analysis • Social and ecological impacts
Objective 3	**Best management practices and case studies**	• WSUDP examples

Source: CSE, 2016

Overview of the guide

Table 2: Objectives of the guide indicates how each objective is detailed in the chapters of this report. The objectives, along with the chapters that cover them, are summarized in the following section.

Objective 1: To sensitize practitioners about the need for and concept of WSUDP

Chapters 1 and 2 cover this objective. Chapter 1 defines the objectives of the guide and methodology used to prepare it. It delineates relevant users and the benefits of using this guide. It analyses existing policies, framework and regulations as well as the current scenario of water management and demands direct mention of water management, planning and design.

Chapter 2 explains the term and concept of WSUDP and how it is different from conventional water-management solutions in cities. It highlights different elements of WSUDP along with community development. It discusses the various terminologies used for WSUDP in different countries and how the term WSUDP is best suited to the Indian context.

Objective 2: To provide inputs on WSUDP with regard to planning and designing on different scales.

Chapters 3 and 4 cover this objective. Chapter 3 includes an analysis of WSUDP on different scales. Water-sensitive planning principles are first showcased according to different land uses and water-intensive activities in cities/zones. The focus then shifts to water-sensitive urban design (storm-water management) and to site-level designs.

Chapter 4 discusses the analyses of stakeholders and their importance in WSUDP projects. Social, economic and environmental impacts are also discussed. The application of different types of water-sensitive structures according to respective land uses is detailed. Chapter 4 also includes the importance of operation and maintenance (O&M) along with selected knowhow of a few structures with stakeholder and community participation.

Objective 3: To present case studies in support of WSUDP principles and analyse the relevant tools and techniques.
This guide is supported by case examples of WSUDP measures (Chapter 5).

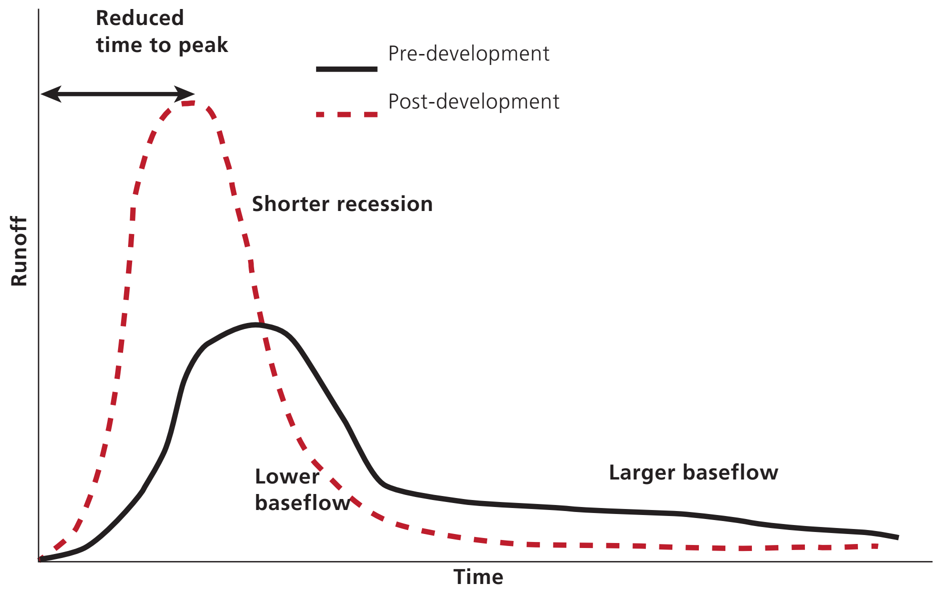
The guide also lists recommended reading material related to WSUDP (see *Annexure B*).

2. Concept of WSUDP

The need for a paradigm shift and new approach

Impervious surfaces in urban areas include pavements, buildings, structures and, in some cases, heavily compacted urban soils. With vegetation removed and hard surfaces created, rainwater infiltration and natural groundwater recharge decreases, resulting in increased runoff rates and volumes and reduced infiltration, groundwater recharge and base flow to urban streams. The altered hydrology causes environmental impacts, including downstream flooding, stream-bank erosion and stream down cutting, deteriorating water quality due to increase in sediment, nutrients and heavy metals, and a decline in aquatic biota (see *Figure 4: Hydrologic patterns before and after development*).[1]

Figure 4: Hydrologic patterns before and after development

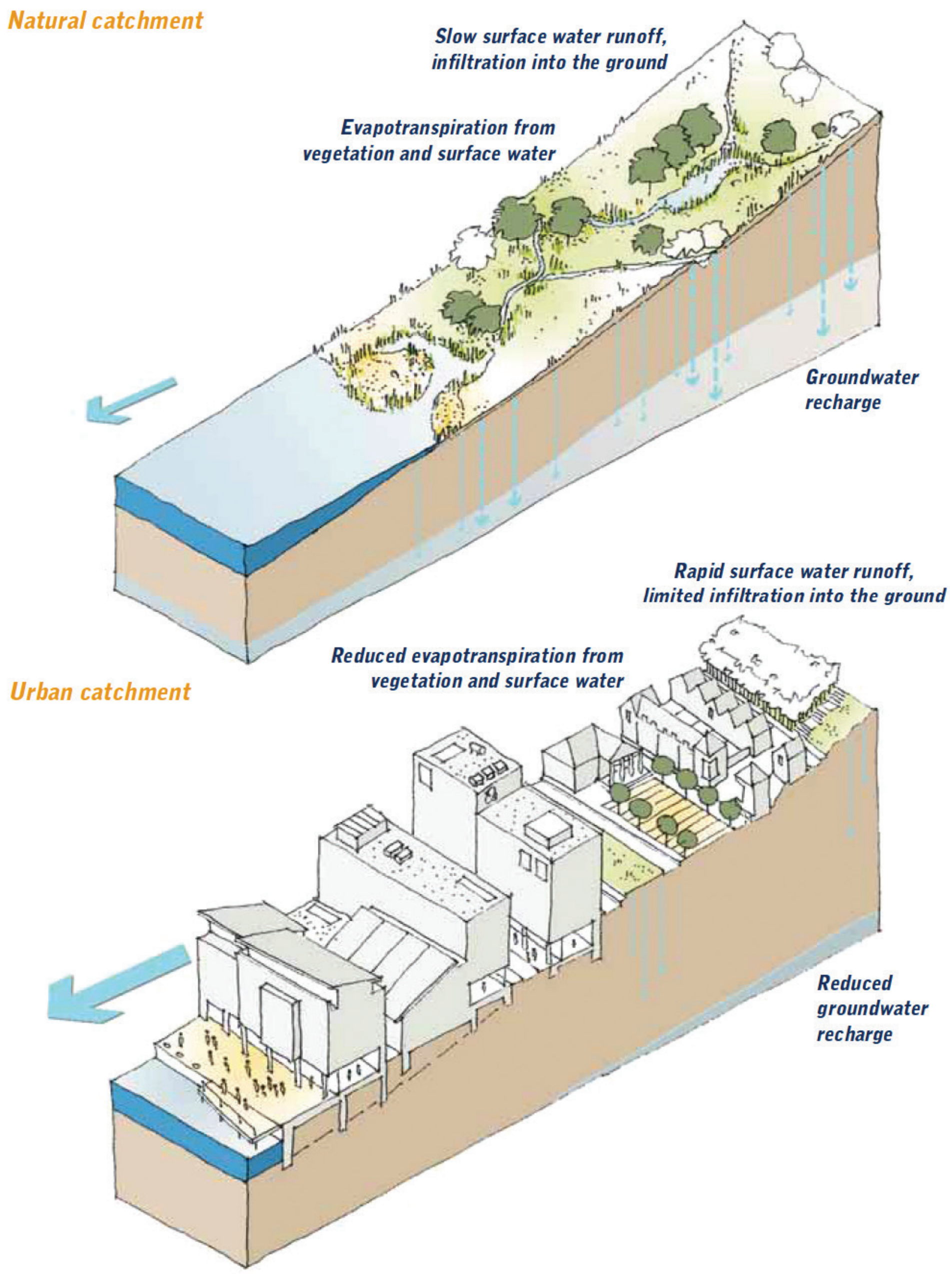


Source: Liu, J., Sample, D.J., Bell, C. and Guan, Y., 2014. Review and research needs of bioretention used for the treatment of urban stormwater. Water, 6(4), pp. 1069–99.

Urban development can, however, be planned and executed so as to lower the hydrological impact of urbanization by using current opportunities to increase the carrying capacity of the area in terms of improved water management (see *Figure 5: Conceptual framework: Need for WSUDP approach*). WSUDP, being the integrated design of the urban water cycle, incorporating water supply, wastewater, storm-water and groundwater management, urban design and environmental protection, can contribute towards sustainability and livability, particularly when considered as part of an overall urban strategy.[2]

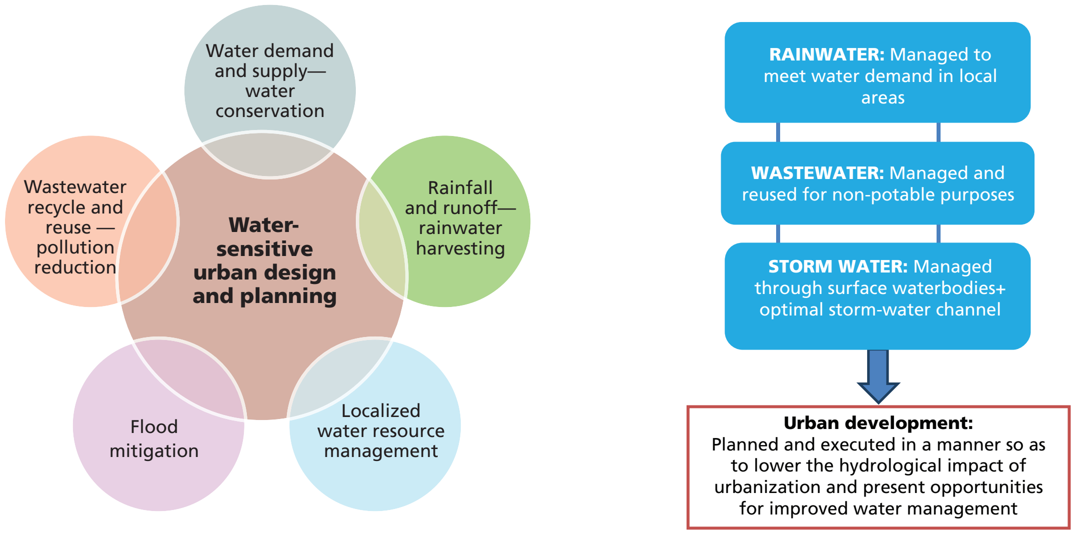
WSUDP has been identified as a means to control flows and filter storm water to remove pollutants. It offers the potential to reduce the costs, infrastructure sizing and occupied land area associated with conventional drainage approaches whilst treating runoff closer to its source.

Figure 5: Conceptual framework: Need for WSUDP approach



Source: Dickie, S., McKay, G., Ions, L. and Shaffer, P., 2010. Planning for SuDS–making it happen. CIRIA Publication C, 687.

Figure 6: WSUDP: Integrating water-cycle management



Source: CSE, 2016

What is water-sensitive urban planning and designing?

WSUDP is an approach that integrates and optimizes the use of available water sources and completes the water cycle by incorporating the following in planning and designing[3] (see *Figure 6: WSUDP: Integrating water-cycle management*).

- Protecting local waterbodies (lakes, ponds and wetlands) for supplementary water sources
- Storm-water management at public places, including open areas in cities through elements of landscape design (e.g. vegetated swales and buffer strips, bio-retention systems)
- Recycling and reusing wastewater naturally (low cost/low energy) and not treating it as a liability
- Increasing water-conservation approaches at various scales (buildings/campus)—i.e. by adopting water-efficient fixtures, xeriscaping landscape (i.e. planting native species) and using water-efficient irrigation methods—thereby minimizing load on the municipal supply system and groundwater sources. On-site water conservation with rainwater harvesting (RWH) is also important to reduce water scarcity.
- Adding value to the social and ecological aspects of areas by planning and designing the built environment in accordance with community needs and water issues
- Connecting the urban water cycle by collaborating with practitioners of different disciplines to bring different perspectives and expertise
- Associating upcoming policies, regulations and approvals with WSUDP[4]

The sustainability approach needs to include elements of water quantity, water quality and ecology, along with community involvement. Therefore, prime potential sustainability factors to facilitate accreditation of water-management options with regard to capital cost, resource use, performance and maintenance are technical, environmental, social and economic elements related to WSUDP (see *Table 3: Components of water-sensitive urban design and planning*).

Table 3: Components of water-sensitive urban design and planning

Sustainable water management					Urban planning				Landscape design	
Ensure water supply	Manage storm water	Treat/ recycle waste-water	Ensure/ improve waterway health	Protect surface water-bodies and groundwater	Consider ecological demands	Consider economical demands	Consider social demands	Consider cultural demands	Provide aesthetic quality	Contribute to cities amenity
Engineers		Environmental scientists		Environmental planners	Urban and landscape planners	Administrative officers		Architects/ engineers	Landscape architects	Urban designers/ architects

INTEGRATE

MANAGE WHOLE WATER CYCLE
CONTRIBUTE TO SUSTAINABILITY IN URBAN AREAS
PROVIDE CONDITIONS FOR HUMAN-SCALE LIVING

Source: Hoyer, J., Dickhaut, W., Kronawitter, L., & Weber, B. (2011). Water sensitive urban design: principles and inspiration for sustainable stormwater management in the city of the future. Hamburg, Germany: Jovis

Table 4: Comparison between conventional practice and WSUDP lists the currently practised and WSUDP approaches for managing urban water resources.

Table 4: Comparison between conventional practice and WSUDP

Conventional approach	WSUDP approach
Fragmented approach: Integration is by accident. Water supply, wastewater and storm water may be managed by the same agency as a matter of historical coincidence but physically the three systems are separated.	**Integrated approach:** Physical and institutional integration is by design. Linkages are made between water supply, wastewater and storm water as well as other areas of urban development through highly coordinated management.
Linear urban water cycle: Water follows a one-way path from supply, to a single use, to treatment and disposal to the environment.	**Closed urban water cycle:** Reuse and reclamation. Water can be used multiple times, by cascading from higher to lower quality needs, and reclamation treatment for return to the supply side of infrastructure.
Increased demand: Increased demand is met through investments in resources and centralized infrastructure leading to leakage losses. Water of potable quality is supplied for all uses.	**Reduced demand:** Options to reduce demand by conservation, harvesting rainwater and reuse. The decentralized system also leads to leakage reduction. Water of potable quality is provided only for uses that require it. Alternative sources are sought for non-potable demand.
Storm water as nuisance: Storm water is conveyed away from urban areas as rapidly as possible.	**Storm water as a resource:** Storm water is attenuated and retained at source allowing it to infiltrate into aquifers and flow gradually into receipting water bodies. Storm-water infrastructure is designed to enhance the urban landscape and provide recreational opportunities.
Bigger/centralized is better: To get water from distant source and then to treat wastewater at far places, thereby increasing the overall infrastructure.	**Small/decentralized is possible:** Make use of the local resource and treat waste near the source with the aim of attaining sustainable and affordable approach.

Source: Adapted from Sen, D.S. 2008. 'Water Management to Water Sensitive Planning—A contemporary approach for sustainable urban development', Presented at training programme on 'Water Sensitive Design and Planning', New Delhi, 2015.

2.1 Evolving knowledge of WSUDP

Evolving international knowledge and experience about WSUDP

The Australia-based Water Sensitive Urban Design Research Group (1989) was among the first to research WSUDP. In the 1970s, USA's USEPA showed the first concern for protection of water quality in streams and lakes from storm-water runoff. In 2006, the British Construction Industry Research and Information Association (CIRIA) subsequently widened the scope and turned from sustainable drainage to sustainable water (and wastewater) management in connection with land-use planning, taking into account social, economic and environmental aspects.

It is evident that India's research on WSUDP was also in line with other countries, although its implementation was stagnant. For example, in 1989, DDA planned Dwarka sub-city as a 'zero run-off city', but could not implement it.

Table 5: Knowledge of WSUDP in various countries summarizes the timeline of the evolution and development of various WSUDP techniques in Australia, USA, Japan, UK, Canada, New Zealand, Israel, South Africa and India.

Table 5: Knowledge of WSUDP in various countries

Year	Australia	USA	Japan	UK	Canada	New Zealand	Israel	South Africa	India
1970		∏							
1989	√								ß
1990		∏							
1993			¥				Ó		
1994	√								
1996		∏							ß
1997				Ψ					ß
1999		∏							ß
2002	√								ß
2003							Ó		
2004	√								
2005						Ω	Ó		ß
2006	√			Ψ					ß
2007		∏							
2008					ᴥ				
2012									ß
2013				Ψ				↕	ß
2014								↕	

√	Bekele and Argue first connected urban planning with storm-water management. In 2002, Taylor and Wong published technical reports on best management practices for treating storm water.
∏	Low-impact development was pioneered in Maryland in 1999.
¥	Herath et al. 1993 and Musiake et al. 1999 developed models aiming at flood protection and urban stream restoration.
Ψ	In 2006, CIRIA widened the scope from sustainable drainage to sustainable water (and wastewater) management.
ᴥ	In 2008, British Columbia and Canada used a mathematical model that enables planners to assess and compare the effectiveness of alternative development plans with regard to rainwater management and green infrastructure appeal.
Ω	Van Roon et al. 2005 and van Roon 2007 did extensive research on an integrated urban and rural design and development process.

Ǿ	Developed models to simulate the differences in runoff volume and infiltration between impervious areas connected to pervious ones.
↕	Developed framework and guidelines on water-sensitive urban design for South Africa.
ß	In 2012, the first major step was taken when MoHUA suggested an index for waterbody rejuvenation, groundwater recharge/RWH and flood moderation development, and issued an advisory to ULBs on 'Protection, conservation and restoration of waterbodies in urban areas'.

Source: CSE, 2016

The concept of WSUDP, which integrates the management of different water resources, is being applied in several countries around the world (see *Table 6: Concept of WSUDP used worldwide*).

Table 6: Concept of WSUDP used worldwide

Concept	Country
Water-sensitive urban design (WSUD)	Australia
Low-impact development (LID), best management practices (BMP)	USA
WSUD, sustainable drainage system (SUDS)	UK
Decentralized rainwater/storm-water management (DRWM)	Germany
Sound water cycle on national planning (SWCNP)	Japan

Source: CSE, 2016

2.2 Scope of WSUDP intervention in Indian cities

There is growing realization at the Central/state level that the risk of not addressing water management in the early stages of planning and design causes constraints to new development or (re)development, missed opportunities for cost saving, poor quality of urban environment and overall unsustainable urban development. The need is for more integrated land and water management from early stages to reduce the increasing water footprint of urban centres.

WSUDP strategies, after being planned and designed correctly, offer an opportunity to intervene not only in private development but also in planning development documents. WSUDP helps achieve a sustainable balance between overall development and environment (see *Table 7: Scope of WSUDP interventions as per existing provisions).*

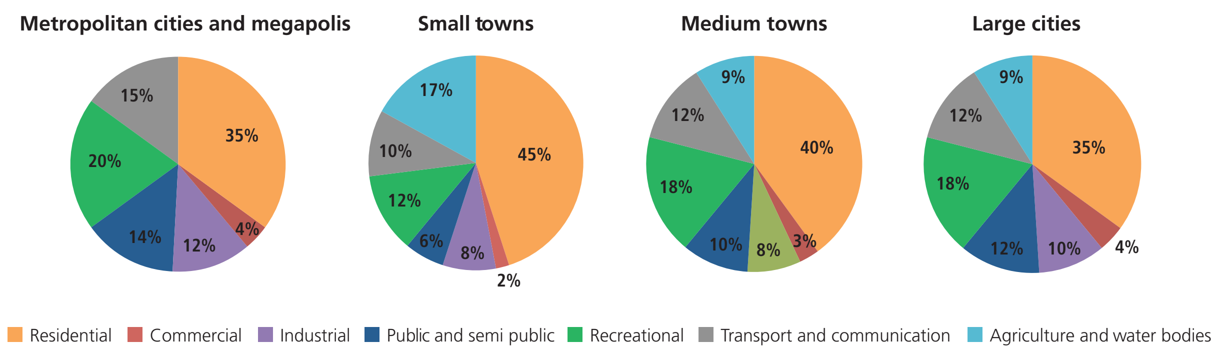
Guidelines and data from Urban and Regional Development Plans Formulation & Implementation (URDPFI) have been taken to prepare the proposed land-use breakup for different urban centres (see *Figure 7: Land-use pattern for different urban centres of India*). According to guidelines, the maximum percentage of land is allotted to residential areas in different sizes of urban centres—metropolises to small towns. Residential clusters, which occupy the largest share of land use in cities and towns, comprise building rooftops, sidewalks, paved parking spaces, pervious areas that could be gardens or just open land and accessible roads.

Table 7: Scope of WSUDP interventions as per existing provisions

Scale	Existing documents/provisions	Opportunities
City level: Open spaces—parks and waterbodies, road infrastructure (planning stage)	• Master plans (20 years) • City development plan (five years) • City sanitation plan • Environmental management plan	• Waterbodies, parks, recreational areas, green areas, public and transport • Future locations of storm-water management facilities and proposed STPs
Zone level (planning and designing stages)	• Zonal plan • Storm-water management including water bodies • ULB schemes and sanitation schemes • Detailed project reports (DPRs)	• Parking lots, roads, parks, open space blocks and storm-water management facilities defined in planning documents • DPRs for water supply, sewerage including STPs, sanitation, storm-water drainage
Individual level (designing stage)	• Site plan—guided by bylaws	• Site-specific on-site water-sensitive facilities • Water-efficient fittings, sustainable landscaping, RWH and wastewater recycling and reuse.

Source: CSE, 2016

Figure 7: Land-use pattern for different urban centres of India



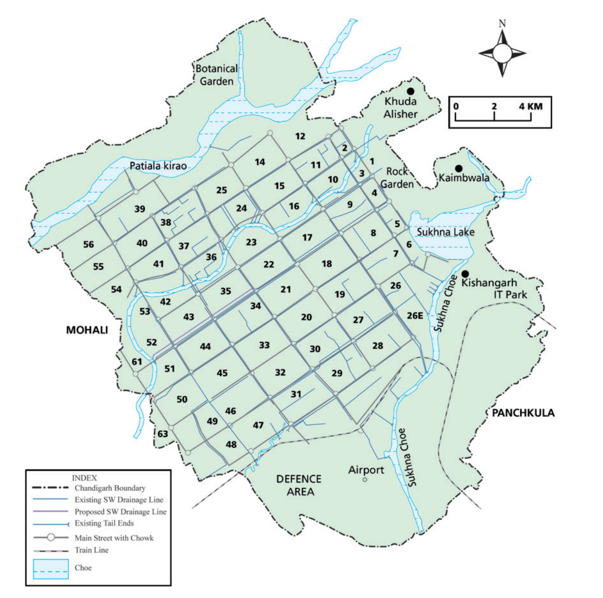
Source: Urban and regional development plans formulation and implementation (URDPFI) guidelines (2014), Ministry of Urban Development

The following section showcases an overarching framework of potential WSUDP systems that can be implemented in an urban area, depending on the physical and land-use features. Extensive research that has been done identifies the enabling environment and potential of WSUDP intervention in three cities of India. Implementation of WSUDP systems in different cities of India can contribute significantly to addressing the water demand–supply gap, dealing with water logging/flooding and recharging depleting aquifers.

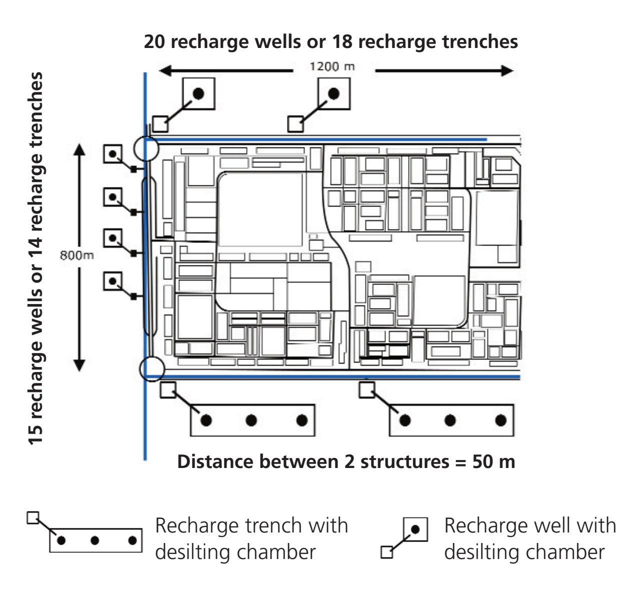
Some of the following case studies showcase the scope and potential of WSUDP at the city/zonal scale. Cities can adopt these strategies that have been implemented and practised successfully.

CASE STUDY: Scope of RWH intervention, Chandigarh, India

Year of research: 2010



Storm-water drainage system in Chandigarh city



Proposed recharge structures in Sector 20, Chandigarh

Features

How and where can RWH be undertaken in the city?

- By recharging the deep, confined aquifers
- By storing water in tanks or ponds and waterbodies

Results/observations

The RWH potential of Chandigarh, with an area of 114 sq. km, assuming a co-efficient of 50 per cent, and the average annual rainfall of 1059.3 mm is 60,380.1 million litres, or 13,241.25 million gallons or 36.28 MGD. This is more than the water pumped out of aquifers and, therefore, harvesting and recharging rainwater will go a long way in contributing towards sustainability of water supply.

Description

Chandigarh has grown rapidly in the last decade (1991–2001). Its population growth rate was 40 per cent. Its population density of 7,900/ sq. km is one of the highest in the country and it is estimated that its demand for water will grow steeply. By 2025, the city's demand for water is estimated to be 800 MLD, an increase of 58 per cent over the 2011 demand of 494.25 MLD.

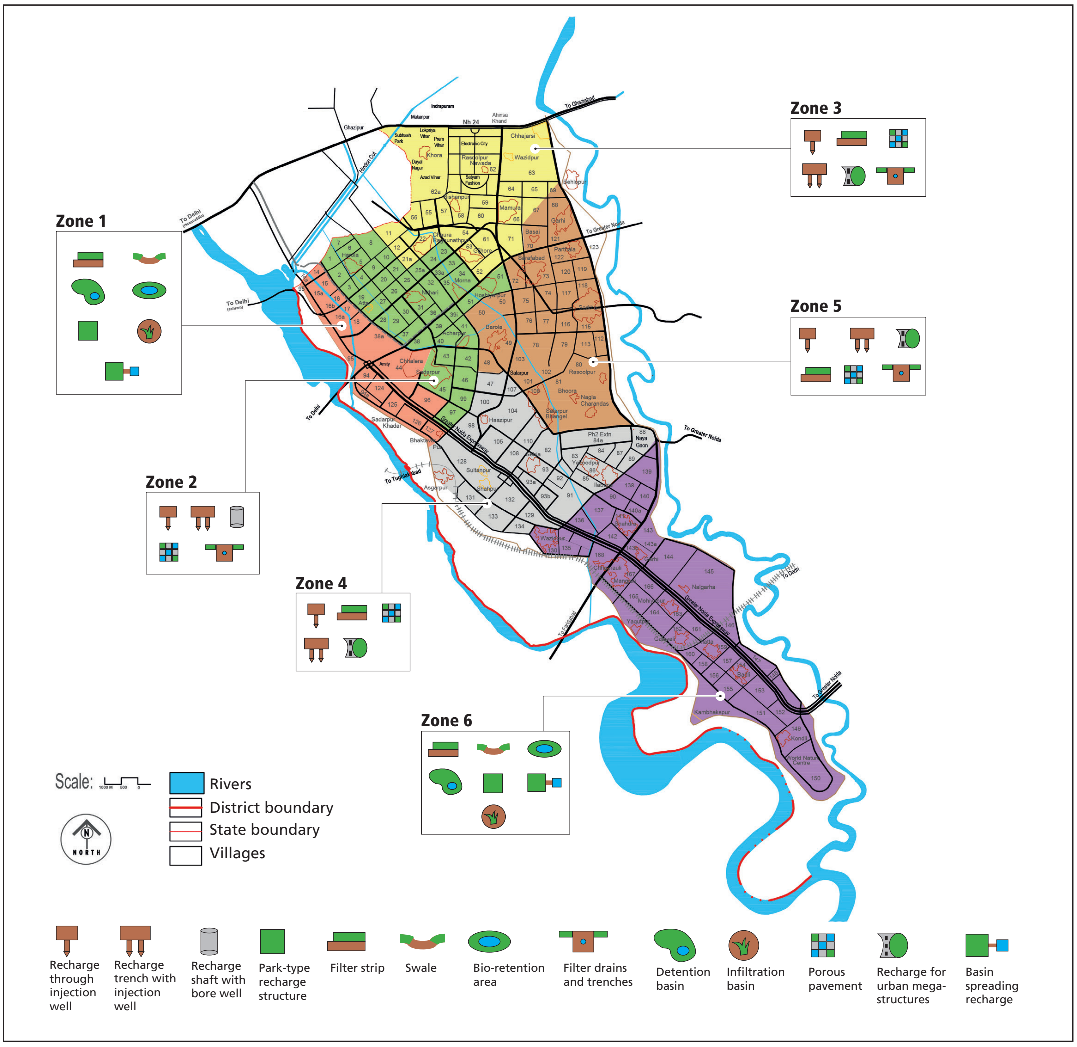
To ensure long-term sustainability of water sources for the city, RWH is a simple and effective solution. It can be done using roads, roundabouts, parks, rooftops, paved areas in almost the entire city.

The storm-water network collects water from roads (15.89 sq. km), rooftops of residential areas, (30.19 sq. km), shopping areas (3.97 sq. km), and public and institutional buildings (7.94 sq. km). This amounts to over 70 per cent of the total land area. The total quantum of water that would be available for recharge annually would be 58 sq. km (area) x 1059.3 mm (rainfall) x 0.5 (rainfall coefficient) = 30,720 million litres (18.46 million gallons per day [MGD]). This is equivalent to almost 90 per cent of the total groundwater supply and is available only from tapping the storm-water-drain network. By careful planning of recharge in parks and green areas of the city, it would be possible to recharge the entire groundwater the city takes out.

Source: Water Management Team, 2010. *Capturing Rainwater: A Way to Augment Chandigarh's Water Resources*, CSE

CASE STUDY: Scope of RWH intervention, Noida, India

Year of research: 2017



Description

Noida requires an unparalleled infrastructure of sustainable water management. However, unregulated and increasingly unsustainable exploitation of aquifers has led to a decline in the water table and deterioration in the quality of groundwater in the area. The projected increase in the proportion of hard surface has further increased runoff while decreasing percolation in the area.

The overarching framework of RWH systems that can be implemented in the area depends on its physical and land-use features. Implementing RWH systems in Noida can contribute significantly to addressing the water demand–supply gap, dealing with waterlogging, flooding and recharging aquifers.

Source: Suresh Kumar Rohilla, Shivali Jainer and Mahreen Matto, 2017. *Mainstreaming Rainwater Harvesting in Noida*, Centre for Science and Environment, New Delhi.

Features

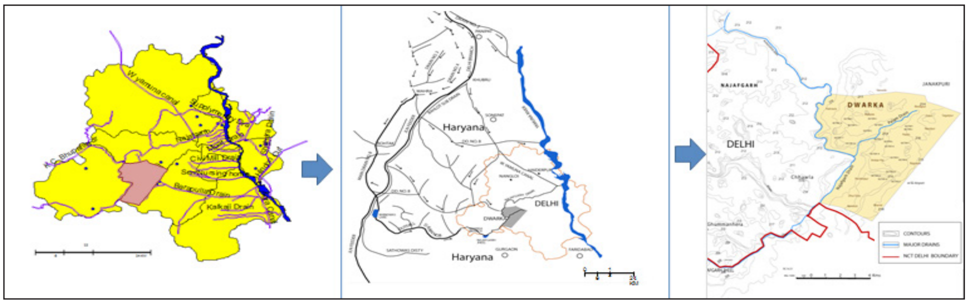
The RWH potential of Noida is about 27.73 million cubic metres (MCM) (i.e. 27,730 ml), which can meet 26.63 per cent of its annual water demand.

If Noida implements RWH intervention:

- An additional 5 MCM (5,000 ml) unutilized Yamuna floodwater could be harvested to augment water supply.
- A reduction in water demand by 26.6 per cent can be achieved if the full potential of rainwater is used in Noida.

CASE STUDY: Scope of WSUDP intervention, Dwarka, New Delhi, India

Year of research: 2012



Description

The objective of this case study is to provide sustainable solutions by showcasing interventions with regard to planning current Indian urban areas.

To identify and analyse the issues and challenges of water management in the India's capital New Delhi, it is pertinent to note that the population of Delhi has been projected to cross 20 million by 2021. Housing projects such as Dwarka were envisaged in early 1990 to accommodate approximately one million people. However, the master plan makes no distinction between semi-urban/peri-urban areas and areas in transition, such as Dwarka sub-city. Hence, there are no specific norms or recommendations for these areas, resulting in a wide demand–supply gap.

An analysis of the area is conducted in terms of three main areas: storm-water management, water-supply management and wastewater management. Dwarka site was analysed with WSUDP approach leading to proposals and conclusions for each of the water resource integrating with spatial planning.

1. Storm-water management

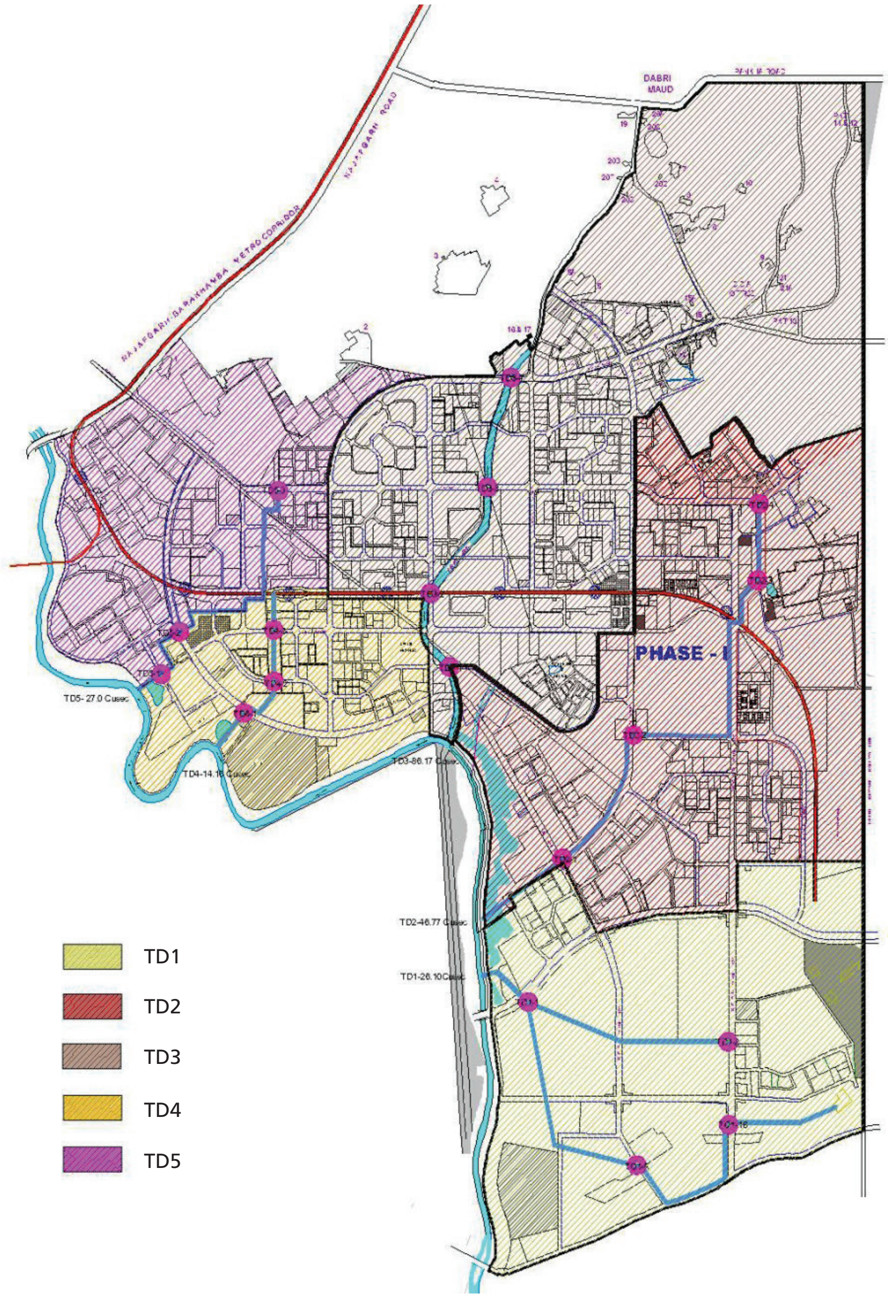
Steps for analysis:

i. Delineation of catchment areas and sub-catchment areas according to trunk drain
ii. Calculation of additional runoff discharge in peak hours for storms over 25 years for the respective watersheds by the rational formula (Q = CIA). (In the case of Delhi, the intensity of one-hour peak rainfall is of 90 mm/hr for storms over 25 years.)
iii. Identifying potential sustainable strategies based on site characteristics and pollution levels according to land-use characteristics in different watersheds
iv. Preparation of matrices for suitable strategies for sustainable urban drainage systems at the watershed and neighbourhood levels (for different land uses) and listing out other environmental benefits

Planning proposals are provided for:

i. Catchment area for reduction in overall runoff coefficient of Dwarka
ii. Increase in retention areas in Dwarka and formulation of matrix as a guideline of different SUDS structures according to different public open spaces.
iii. At site level—Integrated approach for SUDS is proposed accordingly for sites with area less than 1,000 sq. m and greater than 1,000 sq. m.
iv. Management proposals are given in the form of O&M requirement for SUDS

Increase in discharge exceeding the designed drains in Dwarka



Delineation of catchment areas, Dwarka

Trunk drains	Discharge capacity (cusecs)	Area	Required capacity (cusecs)	Increase in discharge (%)
TD5	27	485	67.80	151.10
TD4	14	324	48.58	247.03
TD3	86	1278	206.69	140.33
TD2	47	920	131.97	180.78
TD1	26	85	134.47	417.19

2. Water-supply management

Steps for analysis:

i. Evaluating the current water supply scenario in Dwarka
ii. Accessing potential water quantity on-site, comprising runoff, groundwater, wastewater and floodwater
iii. Calculating the sustainable quantity if all the sustainable drainage strategies are applied and regional water collection in potential site area and present MCD supply is taken into consideration
iv. Accessing water supply and demand projection by present and projected water supply cost–benefit scenario

Policy proposals are provided for:

i. The use of potential sources of water rather than conventional water sources in Dwarka
ii. Cost-efficient water use for residential purposes by installing water-efficient fixtures, reusing wastewater and incorporating water-conserving landscaping
iii. Segregating water resources for bulk use to leverage the total potential of low-lying area of the site

3. Wastewater management

Steps for analysis:

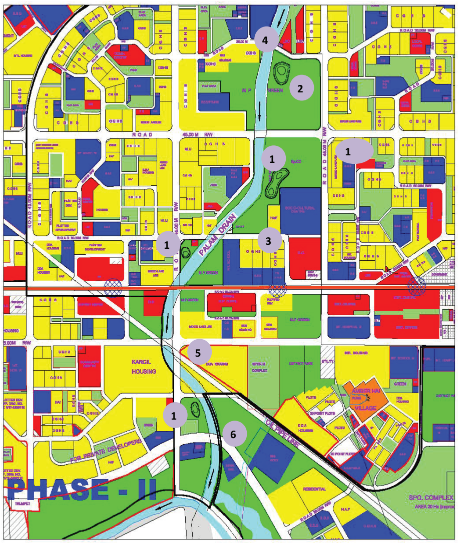
i. Calculating the potential grey water that can be reused, listing the currently used conventional infrastructure and calculating the cost incurred by using the same techniques
ii. Listing out the different natural decentralized techniques that can be used for treatment along with the cost and the area required for them. This leads us to propose the purposes for use of treated wastewater in Dwarka.

Proposal and conclusion:

i. Planning proposals are provided at the site level for provision of waste management on site
ii. A matrix is used as a guideline to different natural systems with cost and area required given along with management proposal for provision of safe disposal of unused treated wastewater

Proposal for provisions of different natural wastewater systems, Dwarka

Conventional infrastructure	Required infrastructure	Decentralized infrastructure	Other benefits with reference to Dwarka
Sewage treatment plant (STP)	Present STP capacity—20 MLD Infrastructure required for 40 MLD	Reed bed system, DWWTs	• Group housing and institutions can be incorporated in accordance with the landscape • No nuisance and odour • Highly efficient method reduces BOD up to 95 per cent. • Area required (sq. m): 1/cum to 8/cum
Underground sewage system	Dwarka Phase-II development for four neighbourhoods (0.8 x 0.9 km)	Septic tank, Biotoilets	• Small space required • Length of pipeline is reduced • Grey water can be reused for non-potable purposes • Area required (sq. m): 2/cum to 7/cum



1. Detention ponds
2. Bio-retention areas
3. Gully and trench
4. Check dam
5. Filter strips
6. Grassed swales

SUDS	Features
Open spaces	Ponds and wetland
	Infiltration and retention basins
	Filter strips
	Swales
	Rain gardens (bio-retention)
	Filter drains
	Canals and rills
Roads	Filter strips
	Swales
	Rain gardens (bio-retention)
	Filter drains

The strategies are applied at the following scales:

- Neighbourhood scale: For different plot areas, bylaws are proposed for RWH and minimum green area provision.
- Catchment scale: Various natural drainage structures (such as swales, bio-retention area, ponds and trenches) are designed according to identified public open spaces of Palam drain catchment area.
- Regional scale: Potential areas for regional floodwater harnessing are identified. A series of ponds are proposed to carry additional floodwater (6 MCM annually). The harnessed water is used for horticulture and construction purposes.

Sources:

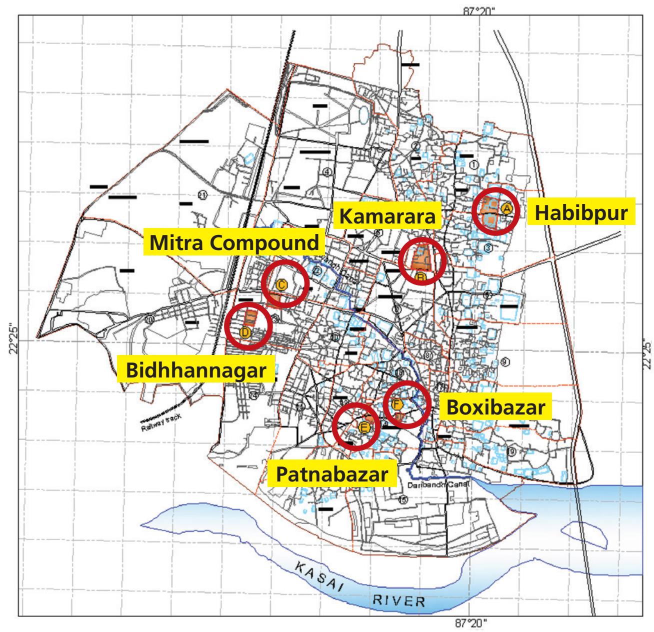
Rohilla, S.K., 2012. Water, City and Urban Planning: Assessing the Role of Groundwater in Urban Development and Planning in Delhi, Centre de Sciences Humaines. No. 31-2012.

Jainer, S. 2012. Stormwater Drainage and Resource Management Case Study, Dwarka. New Delhi. (Master dissertation, S.P.A. New Delhi. Unpublished).

Rohilla, S.K., 2007. Groundwater and city planning; Building a case for water sensitive urban planning in Delhi in Spatio-Economic Development Record, vol. 14. no. 3 (May–June).

CASE STUDY: Water-sensitive urban development planning provisions in residential cluster level, Medinipur Town, West Bengal, India

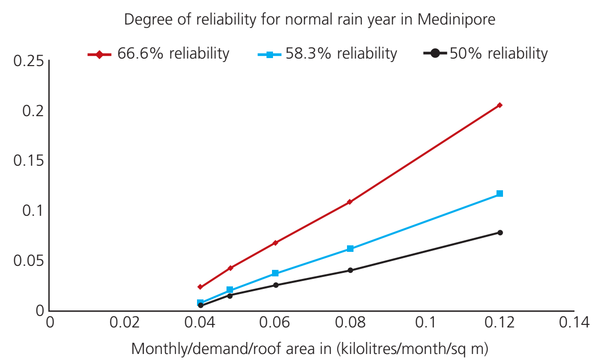
Year of research: 2003



Selected areas for detail investigation in Medinipur town

Description

Medinipur Town lies in West Medinipur district of West Bengal with a municipal area of 18.13 sq. km and total population (2001) of 149,768. The current municipal water supply is 83 litres per capita per day (lpcd) and future municipal water supply is projected to be 125 lpcd. Several micro-catchments areas are selected within the town to study the existing water-management scenario. The study relied heavily on primary survey data, published data and existing mathematical models available in various literatures. The presumed hydrological water year was taken to be from 1 January to 31 December of each calendar year. It was assumed that the entire impervious surface comprising roofs, paved surfaces and roads did not change significantly within the plotted development during the period of study.



Cluster plan for one of the six study areas in Medinipur site: Kamarara	Reliability of rainwater tank for water substitution, Medinipur

Findings from household survey on hydrological front

Per capita water use for kitchen (average 15 lpcd), which includes drinking water requirement (average 16 per cent of total water use), does not vary much over the six study areas. Water use per capita for bathing (27–37 per cent of total water use), washing (9–31 per cent) and toilets (20–36 per cent), on the other hand, vary to a large extent over the study areas. Further, water use per capita for washing and toilet purposes vary in the range of 31–35 lpcd to about 53–55 lpcd. Water for these uses need not be of potable quality and could be substituted by stored rainwater in the premises.

It was observed that with the increase in urbanization, there is a general increase in per capita water requirement by the inhabitants, irrespective of household size.

Findings from analysis on catchment front

Values of impervious/pervious area ratio of the clusters were considered to represent various surface sealings (applicable to plots with buildings, pavings and approach roads). Values of roof/pervious area ratio of the clusters were considered to represent built coverage (applicable to large plots that have buildings, with no approach road or paving).

In the case of annual rainfall versus annual runoff analysis, there is a linear relationship between annual rainfall and runoff. As the amount of rainfall gradually increases from a dry year to a wet year, annual runoff increases extensively from a moderate 50 per cent to a high 80 per cent of the annual rainfall for the same area. Again, for the same rainfall year, the annual runoff varies appreciably from 65 per cent to 75 per cent to 85 per cent of the annual rain with the change in the customized curve number (CN) value for different clusters.

Study inferences

- For every 20 per cent increase in annual rainfall, the average runoff increases by about 30 per cent to its previous value.
- For the same rainfall year, the annual runoff varies from 65 per cent to 75 per cent to 85 per cent of annual rain as the customized CN value changes from 75.5 to 85.7 to 91.6, respectively.
- A linear relationship has been found between annual runoff, impervious/pervious ratio and roof/pervious ratio among all the six residential clusters under the study area for all rain years.
  It was derived from a multivariate linear regression that annual runoff from a plotted urban residential cluster is very much a function of the following three key parameters:
  i) Annual rainfall
  ii) Impervious/pervious ratio and
  iii) Roof/pervious ratio
  The derived equation could be expressed as
  Run off = (-) 492.88 + 0.97* P + 70* R1 + 5.63* R2
- The derived multivariate linear regression equation can be used elsewhere for making a sensitivity analysis at the residential cluster level by changing the parameter values to accommodate local variations.

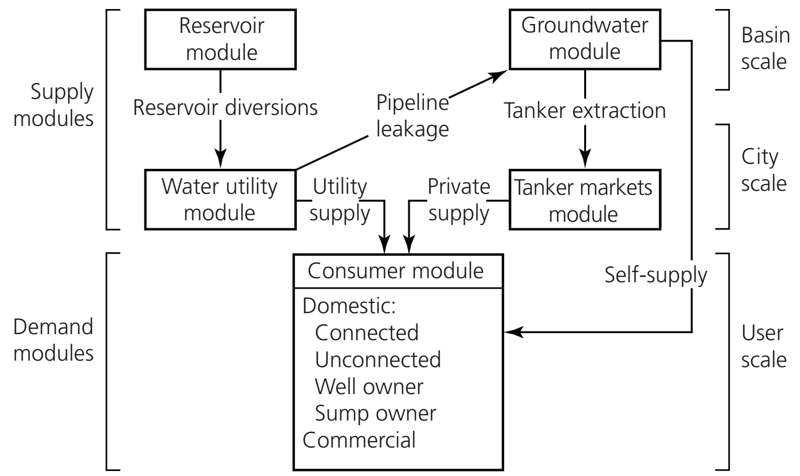
Source: Sen, S., 2013. Presentation on Sustainable Water Management, CSE-COE, CBUD, May 14–17, 2013, CSE, New Delhi

Observations

The analysis reveals that even in a detached house with an average roof area of 100 m^2, six-kilolitre rainwater storage tank capturing the roof runoff (24 per cent of annual rain) could satisfy the monthly water demand (@ 40 lpcd) for five occupants with a reliability of 50 per cent (six months) in all rain years. Open lined rectangular drains could perform with known reliability (with approximately two hours disposal time) even during sudden cloudbursts, releasing as much as 1,200 litres per hectare per day with a cross-section of 0.38 m width and 0.45 m depth with a slope of 1:200 within the study area.

CASE STUDY: Sustainable urban water supply, Chennai, Tamil Nadu, India

Year of research: 2009



This integrated model was constructed to simulate all the components of the Chennai water system

Features

- The research presents an integrative framework uniquely suited to evaluating both centralized and decentralized policy solutions
- By applying this framework, this research was able to come up with new policy insights.

Results/observations

The results suggest that having a reliable source of non-potable supply will boost consumers' willingness to pay for high quality, reliable piped supply and make demand more manageable. However, a transitional solution that employs a combination of rooftop RWH and tariff increases can provide the necessary transition in a manner that is cost effective.

Description

This research proposes a framework to simulate water supply and demand in a simulation model of Chennai, India. Three very different policies, supply augmentation, efficiency improvement and RWH were evaluated using the model. The model results showed that none of the three policies perfectly satisfied the criteria of efficiency, reliability, equity, financial viability and revenue generation. Instead, a combination of RWH and efficiency improvement best meets these criteria.

The following analysis evaluates the model:

- Considering four dimensions of water supply relevant to consumers: Modes of supply accessed by consumers; investments made by consumers in acquisition, storage and treatment of water; quality of water and time periods in which consumers make decisions
- Distinguishing between short-run decisions (by solving the consumers' cost-minimization problem assuming a fixed set of options in a given time period) and long-run decisions (by accounting for consumers' coping mechanisms and thus the choice set available to them)
- Establishing consumer surplus as a common measure of consumer well-being making, regardless of the type of consumer or modes of supply

Source: Srinivasan, V., Gorelick, S.M. and Goulder, L., 2010. Sustainable urban water supply in south India: Desalination, efficiency improvement, or rainwater harvesting? *Water Resources Research*, *46* (10).

CASE STUDY: A metabolism perspective on alternative urban water servicing options using water mass balance, South East Queensland, Australia

Year of research: 2016; Year of implementation: 2011

Description

The objective of this case study of the Ripley Valley Development Area is to test alternative water-servicing scenarios and provide a new perspective to complement broader sustainability assessments of urban water. It proposed new urban development on the fringe of the high-growth, sub-tropical region of South East Queensland, Australia, designed to accommodate 120,000 people/50,000 dwellings by 2030. It was selected because:

i) Being a new urban area, both the pre- and post-development states are assessed
ii) Prior hydrological modelling had been undertaken, providing some of the required data
iii) Alternative water servicing options had been scoped. It presented an opportunity to evaluate innovative solutions for securing water supply in a region predicted to experience water stress with climate change but which also improves its natural environment and enhances livability for its residents. The urban system boundary was defined as the outer edge of the built-up areas with an area of 3,002 ha.

Rainwater and storm-water scenarios

If rainwater or storm water is harvested and used to a conservative extent (in garden irrigation and toilet flushing), a modest reduction in the storm-water runoff ratio (post-development flows relative to pre-development flows) would be expected, reducing it from 2.5-fold to 2–2.3-fold respectively.

In relation to resource efficiency, an internal harvesting ratio of up to 45 per cent could be achieved through rainwater or storm-water use, although in practice around 20 per cent is more likely based on conservative practices. For storm-water use, there could be a small energy saving of 12 KWh/year if use is maximized because pumping at this larger scale can be more energy-efficient, whereas conservative use gives a similar overall energy use to the base case.

Alternative water servicing options	Storm-water use: In urban areas		Rainwater use: In households		
Conservative implementation	Storm-water runoff is harvested from all hard surfaces (roofs, roads, car parks) within the urban system boundary. Volume harvested is assumed to be limited by maximum harvested volume	Storm water is treated by sand filtration and supplied for irrigation within the urban system boundary. Ten per cent of maximum harvestable volume is used to irrigate 304.5 ha designated as open space in the planning scheme (parks, sports fields, green corridors, street landscaping etc.)	Rainwater is harvested from the roofs of residential and commercial dwellings in individual tanks	Volume harvested is assumed to be limited by the maximum harvestable volume and the volumetric reliability of the tanks	100 per cent of harvested volume is used for some sub-potable demand (garden irrigation and toilet flushing)

Wastewater recycling scenarios at different scales

Decentralized grey water recycling at the household scale also reduces demand for external water supplies but comes at a considerable energy cost of 43–80 kWh/year. This is because the on-site treatment (sand filtration and UV disinfection) and pumping are relatively energy inefficient.

Alternative water servicing options	Conservative implementation
Wastewater recycling: In urban area	Wastewater from all residential and commercial dwellings (80 per cent of water supply) is treated at a local wastewater treatment plant to secondary level with disinfection suitable for irrigation, stream discharge and sub-potable use. 5 per cent of treated effluent is used for irrigation within the urban system boundary in the same way as the conservative storm-water use scenario.
Wastewater recycling: Outside urban area	Like wastewater recycling within the urban area, except that treated wastewater is supplied to an adjacent agricultural area 4–8 km outside the urban system boundary. The recycled wastewater is used to irrigate vegetable crops.
Grey water recycling: In households	Grey water from residential and commercial dwellings (approximately 70 per cent of total wastewater) is collected in individual tanks. It is treated using sand filtration and UV disinfection at the property and supplied back to the same property. Of the total 6.46GL/yr, 34 per cent of generated grey water is used for sub-potable demand in residential and commercial dwellings within the urban boundary (garden irrigation and toilet flushing).
Grey water recycling: In appliances	Recirculating showers are installed in all residential dwelling to recycle shower water. Water and electricity for water heating are assumed to be reduced by 70 per cent.

Features

In this study area, several water-servicing scenarios are developed based on various modes of fit-for-purpose water supply (rainwater/storm-water harvesting and wastewater/grey water recycling) at different urban scales (whole urban area, household appliances).

The servicing scenarios are development-based on various modes of RWH and recycled wastewater use fit-for-purpose at different urban scale.

Results/observations

An analysis of the scenario is used to show how it can be used to assess alternative urban water servicing options. The new insights relate to the extent to which alternative water supplies can influence water efficiency and hydrological performance of the urban area.

Source: Farooqui, T.A., Renouf, M.A. and Kenway, S.J., 2016. A metabolism perspective on alternative urban water servicing options using water mass balance. Water Research, 106, pp. 415–28.

3. WSUDP approach on different scales

This section includes the analysis, designing and planning for WSUDP approach at different scales. The following three scales will be used to analyse the applicability of WSUDP approach (see *Table 8: Different scales for implementing WSUDP*).

Table 8: Different scales for implementing WSUDP

Scales	City/zonal scale	Neighbourhood / institutional scale	Individual scale
Areas (sq. m)	10,000–15,000	4,000–5,000	1,000–4,000
Users/population	5,000 (maximum)	200–5,000	5–200
Wastewater generation capacity (kilolitre per day—KLD)	500 (maximum)	20–500	0.5–20
Land uses/activities	Medium density: 200–400 persons per hectare (pph), commercial areas, neighbourhoods, institutional and peri-urban areas	Institutional/ commercial buildings	Residential buildings (plotted/four–five storied)

Source: CSE, 2016

The larger scale, i.e. the city/zonal scale, needs water-sensitive planning while water-sensitive designing can be done at a smaller scale. For example, in urban developed areas, large campuses and plot areas under land use, such as institutional and commercial areas, water-sensitive design can be incorporated. Other peri-urban or newly developed areas that have scope in public open spaces can be approached through water-sensitive planning.

Water-intensive activities are part of day-to-day urban requirements. They are part of the process of their economic development. Bulk water required for public utilities does not always require high quality of water. The quality of water required for maintaining public parks, gardens, public fountains and cleaning public toilets will be different from that essential for potable purposes.

The following sections elaborate the planning and designing of water sensitivity according to water usage pattern and spatial scales of urban areas.

3.1 Water-sensitive planning (city/zonal scale)

Water-sensitive planning can conserve water resources while offering numerous benefits by way of improving the urban environment, reducing the danger of flooding, increasing opportunities for recreation and leisure activities, and reducing flooding damage and cost of drainage systems. Any open space designed according to water-sensitive planning principles provides recreational and visual amenities while filtering runoff that infiltrates to replenish groundwater. It also acts as a detention reservoir designed to reduce flood discharges and pollutant loadings.

The water cycle in urban areas is lost due to excess construction and paved areas, including in major recharge zones such as lake catchments, riverbanks and wetlands. In addition, contamination of existing water resources with sewage adds to the loss of usable water. The need is to maximize use of open spaces to rejuvenate the lost water cycle. Planning for new areas requires allocating land uses according to hydro-geographic layout. The placement of open spaces—recreational areas, roads etc.—plays a major role in complying with the water-sensitive principle.

Significance of open/buffer areas in water-sensitive planning

Open spaces provide the opportunity to combine the function of public open space with habitat retention (trees and watercourses), pollution abatement and storm-water management.

Wetlands/lakes: In densely populated urban areas, lakes and waterbodies are highly contaminated by the inflow of untreated sewage from areas lacking or having inefficient sanitation services. These waterbodies and lakes can be planned with a green buffer area that can act as a treatment zone. Waterbodies play a major role in the natural hydrological cycle and offer healthy recreational spaces. Since the source of the pollution-degrading waterbody may be unknown, these buffer areas act as protective layers.

Recreational areas: Where open spaces are located in consideration with the natural stream system, they can be also used to prevent and mitigate floods by retaining and detaining storm water and to purify and infiltrate runoff, thus recharging groundwater with clean water. Storm water that reaches open spaces may be used for irrigation and as landscaping elements.[1, 2]

Roads and streets: Roads and streets constitute up to 70 per cent of the impervious urban area and serve primarily to transport people and goods. But they also act as important conveyors of storm water; in fact, they constitute the major drainage system that serves as an important flow path when the drainage pipes underneath go beyond their capacity.[3, 4]

Inclusion of storm-water streams in urban fabric: Storm-water streams/watercourses represent natural drainage lines and therefore need to be considered part of the storm-water management strategy for a development site. The concept of storm-water streams in urban fabric recognizes that there are benefits in considering maintenance of water quality, habitat retention and restoration, water conservation and a wider choice of recreational opportunities in an integrated fashion. Watercourses/streams are generally linear-shaped spaces and therefore present a longer frontage to adjacent residential development than square or circular plan forms. They provide accessible open spaces to people. Their linear nature also offers opportunities to integrate off-road pedestrian and cycle paths (see *Table 9: List of water-sensitive planning principles and approaches*).

Table 9: List of water-sensitive planning principles and approaches

Water- sensitive concept	Water-sensitive planning principle	Water-sensitive planning approach
Minimizing runoff volume	Protecting existing natural features and ecological processes	• Disturbance to soil and landscape minimized by maintenance of natural landforms. Waterways protected by provision of a buffer of natural vegetation to urban development • Natural channel design and landscaping used so that the drainage network mimics natural ecosystem
	Maintaining natural hydrologic behaviour of catchments	• Limiting increase in storm-water runoff volume by using natural drainage paths and infiltration basins • Reducing impervious areas and increasing pervious areas
Minimizing runoff discharge	Integrating water into the landscape to enhance visual, social, cultural and ecological value	• Minimizing use of hard engineered structures • Using native vegetation in storm-water management and all landscaping to maximize habitat values • Passing runoff through vegetated patches and/or through the ground, to cleanse the water from pollutants, especially from suspended sediments
	Minimizing sewage discharge into natural environment	• Wastewater treatment on-site or contribution to municipal wastewater treatment and reuse scheme • Reducing flooding at the downstream end of catchment
Minimizing the pollutant load	Protecting water quality of surface- and groundwater	• Control runoff from disturbed areas during the construction phase of the development • All storm-water runoff from hard surfaces is treated through infiltration, sedimentation, storage or biological treatment before leaving the site
	Minimizing demand on the reticulated water supply system	• Rainwater tanks collect roof runoff to supply toilet, laundry and outdoor uses. Houses connected to (or utilize) a grey-water or sewage recycling system to provide an alternative source of water for toilet flushing and outdoor use. • Houses incorporate water-efficient appliances and plants that need little water (preferably of local provenance) grown extensively in gardens
Reusing treated wastewater	Decentralized wastewater treatment for reuse	• Decentralization facilitates reuse within specified urban area • Preference for natural treatment systems that are not energy intensive and don't require highly skilled labour
	Selection of reuse options based on the quality of treated wastewater	• Treatment of wastewater according to purpose of use. Bulk use of treated wastewater in urban areas for street washing, construction, horticulture, firefighting etc.

Source: CSE, 2016 and Carmon, Naomi, and Uri Shamir. 'Water sensitive planning: integrating water considerations into urban and regional planning'. *Water and Environment Journal* 24.3 (2010): 181–91.

3.2 Water-sensitive designing (neighbourhood/institutional scale)

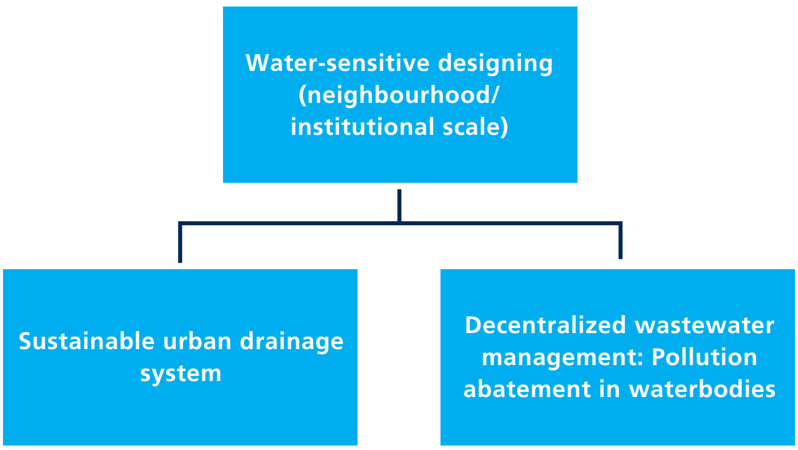
Built-up areas need to be drained to remove surface water. The conventional approach to draining surface water is through underground drainage systems that convey water from built-up areas. These traditional urban drainage systems focus on quantity as they aim to remove excess water from urban areas as quickly as possible to avoid flooding. These drainage systems have not been designed with sustainability in mind. The majority do not pay sufficient regard for flood control, water quality, water resources or biodiversity requirements. Urban drainage systems have caused an alteration in natural flow patterns, not necessarily having an effect locally, but causing flooding problems elsewhere in the catchment area. Water quality has also become an increasingly significant issue as surface run-off from these urban areas results in contamination of the watercourse. Resulting urban flooding is extremely difficult to resolve and is an important issue that drainage systems must take into consideration. In urban areas, continued water management is a necessity and for this to be sustainable, a broad approach to the issue of drainage must be adopted.

A similar situation is encountered with the conventional wastewater management approach which involves centralized systems of sewerage networks to provide treatment and disposal. The conventional technologies of a centralized system of wastewater (sewage) collection and treatment are not just resource-intensive (use of water first to flush, then to carry the waste), but also capital- and energy- intensive. This further makes scope of recycle/reuse bleak as the treated water would again be needed to be conveyed back for reuse and would add to the capital and energy cost.

The alternative approach of decentralized wastewater management is based on the principle of devolving application so that sewage can be treated affordably and treated wastewater can be promoted for local reuse.

The new paradigm for urban design at the neighbourhood/institutional level is to integrate storm water as well as wastewater into existing urban fabric for efficient use of all the potential water resources (see *Figure 8: Water-sensitive designing on neighbourhood/institutional scale*).

Figure 8: Water-sensitive designing on neighbourhood/institutional scale



Source: CSE, 2016

Sustainable urban drainage system

The main objective of storm-water resource management in WSUDP is to integrate storm-water management into the landscape, creating multiple-use corridors that maximize the visual and recreational amenity of urban development.

The following factors govern the scope of implementation of WSUDP measures (see *Table 10: Factors for designing effective sustainable urban drainage systems*).

Table 10: Factors for designing effective sustainable urban drainage systems

Approach for catchment development	Scope of development
Time of concentration—Increase	Lengthening flow paths and conveyance systems. Diverting the drainage flow to bigger areas and open swales
Runoff volume—Decrease	Reducing or minimizing imperviousness, preserving more trees and meadows. Tree plantation along channels as recreational areas
Peak discharge—Reduce	Retention storage for volume and peak control, natural drainage patterns, off channel storage by depressions and through SUDS features
Water quality—Improve	Catchment-land use, sand filters, retention areas, filter strips
Flooding—Controlled	Use of additional runoff, use of floodwater in low-lying area

Source: CSE, 2016

Options and techniques of storm-water resource management in public open spaces

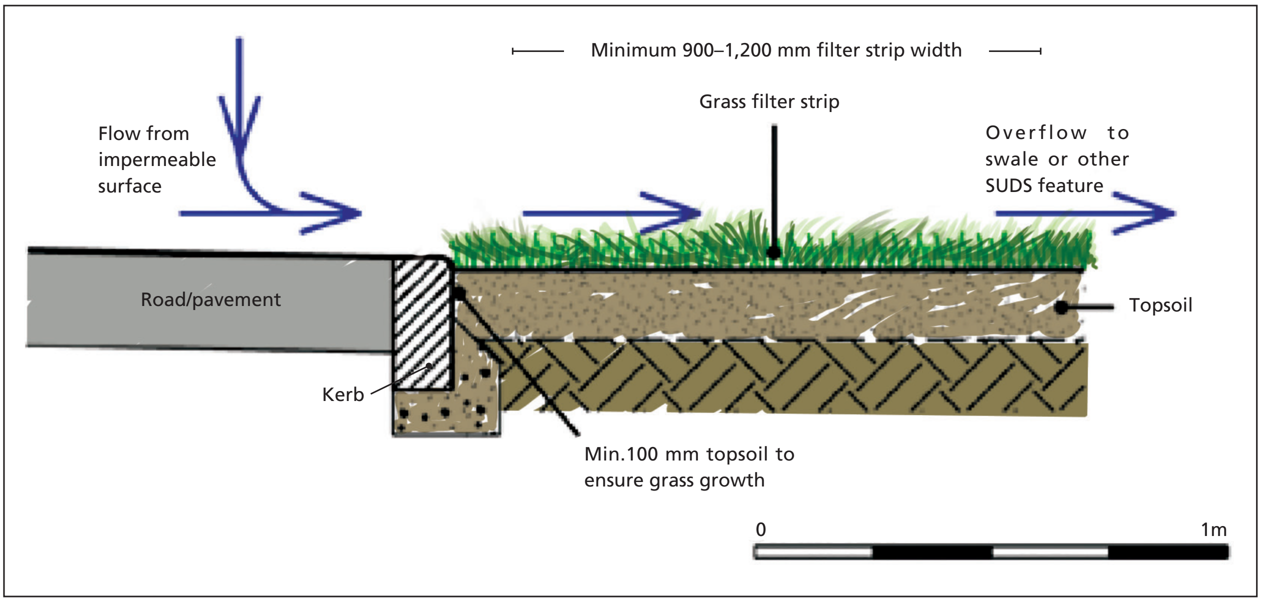
WSUDP measures for a public open space are generally located outside the envelope of individual developments, but in some instances public green space can penetrate into the development and be part of accessible open spaces. Public open space measures are characterized by being located within green space or other clearly defined public areas that can manage the storage and conveyance of surface water runoff. Depending on the design and characteristics of the site there will be a convenient location where the intermediate source control area becomes part of accessible public open space (see *Figure 9: Overview of potential SUDS measures in urban areas*). For designing SUDS, a detail checklist on sustainable drainage systems is provided (see *Appendix C.1*).

Figure 9: Overview of potential SUDS measures in urban areas

Source: http://www.hidrologiasostenible.com/sustainable-urban-drainage-systems-suds/

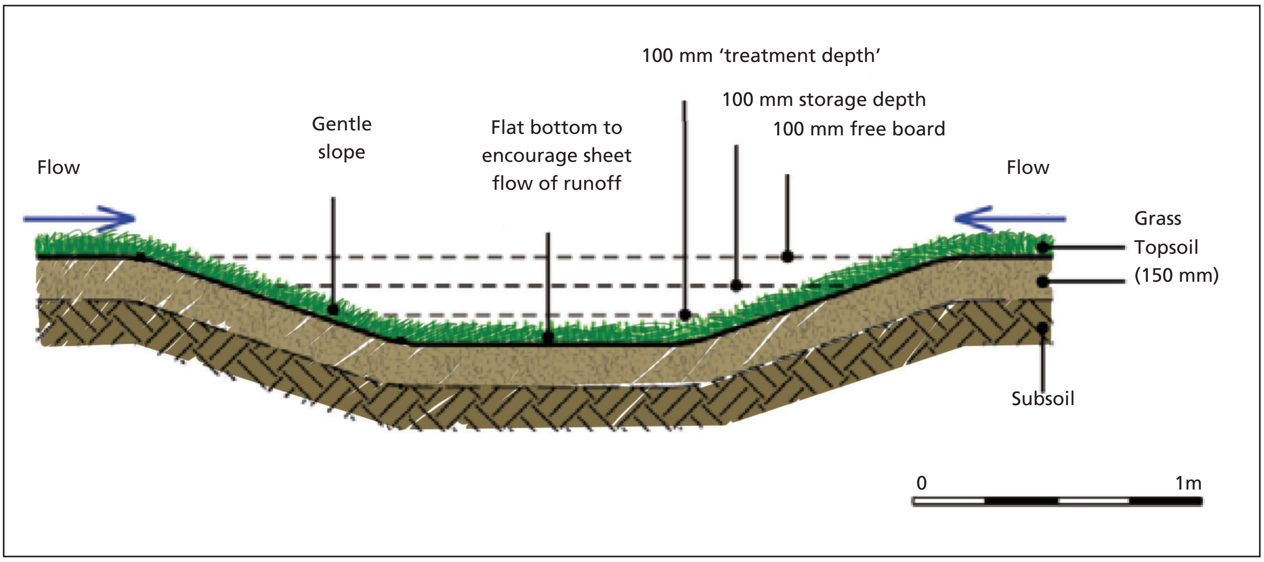
The following are SUDS measures for public open spaces:

Filter strips: Filter strips are grassy or other densely vegetated strips of land that collect surface water runoff as sheet flow from impermeable surfaces.



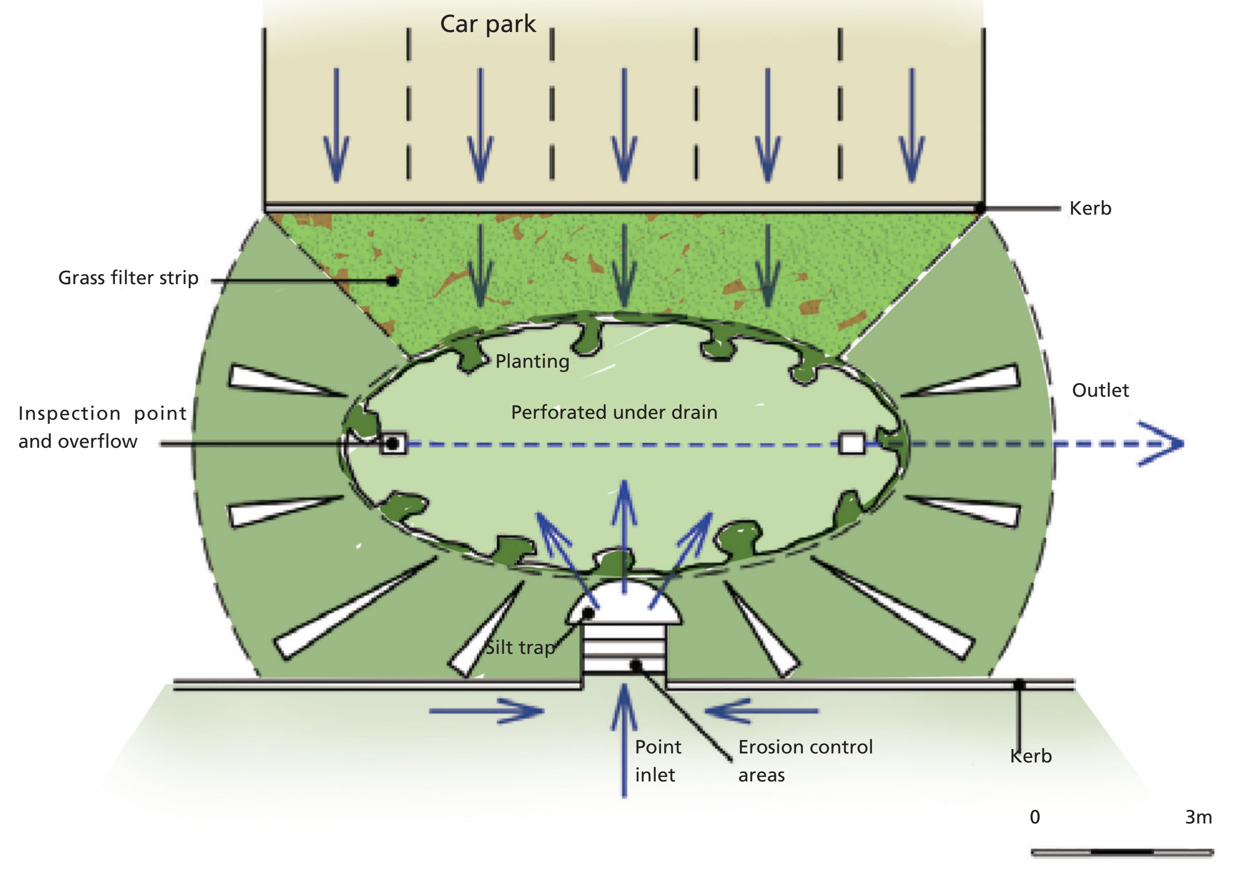
Source: CSE, 2016

Swales: Swales are linear vegetated channels with a flat base that encourage sheet flow of water through grass or other robust vegetation. They collect, convey and sometimes store surface water runoff allowing water to soak into the ground where soil conditions are suitable.



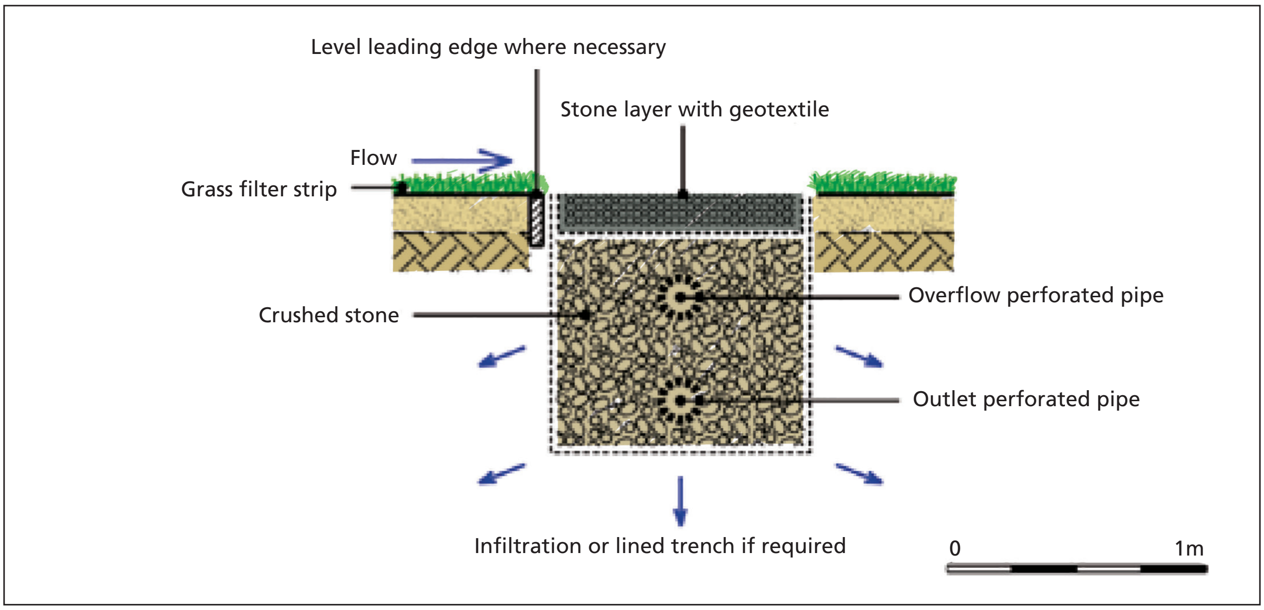
Source: CSE, 2016

Bio-retention areas and rain gardens: Bio-retention areas and rain gardens are planted areas designed to provide a drainage function as well as contribute to the soft landscape.



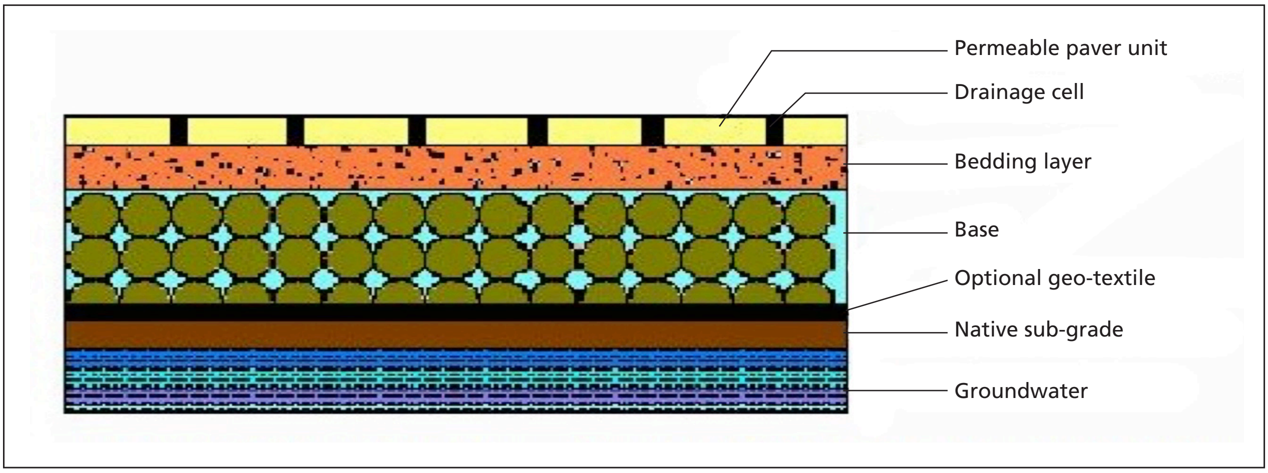
Source: CSE, 2016

Filter drains and trenches: Filter drains and trenches are linear excavations filled with stone that ideally collect surface water runoff laterally as sheet flow from impermeable surfaces. They filter surface water runoff as it passes through the stone allowing water to infiltrate into soil or flow.



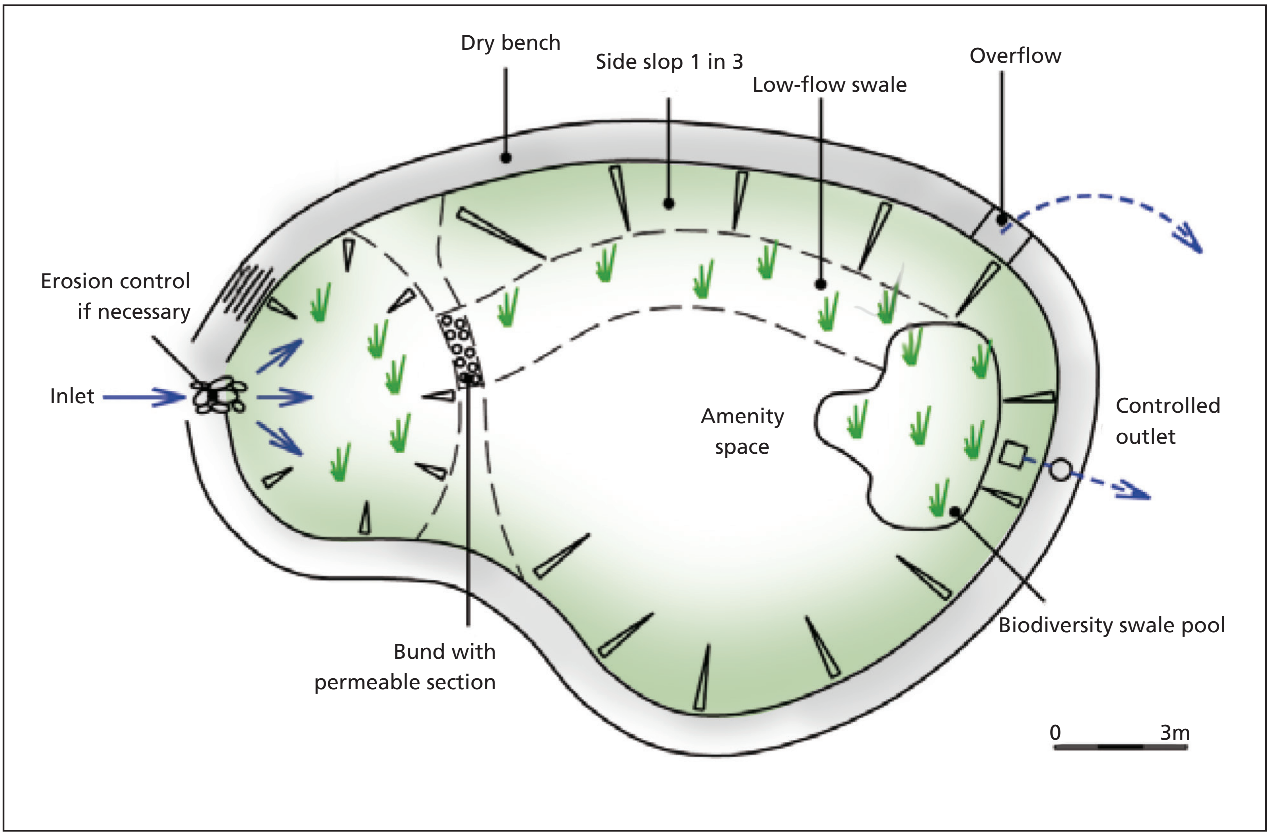
Source: CSE, 2016

Permeable pavements: Permeable pavements provide a surface that is suitable for pedestrian or vehicle traffic while allowing surface water runoff to percolate directly through the surface into underlying open stone construction.



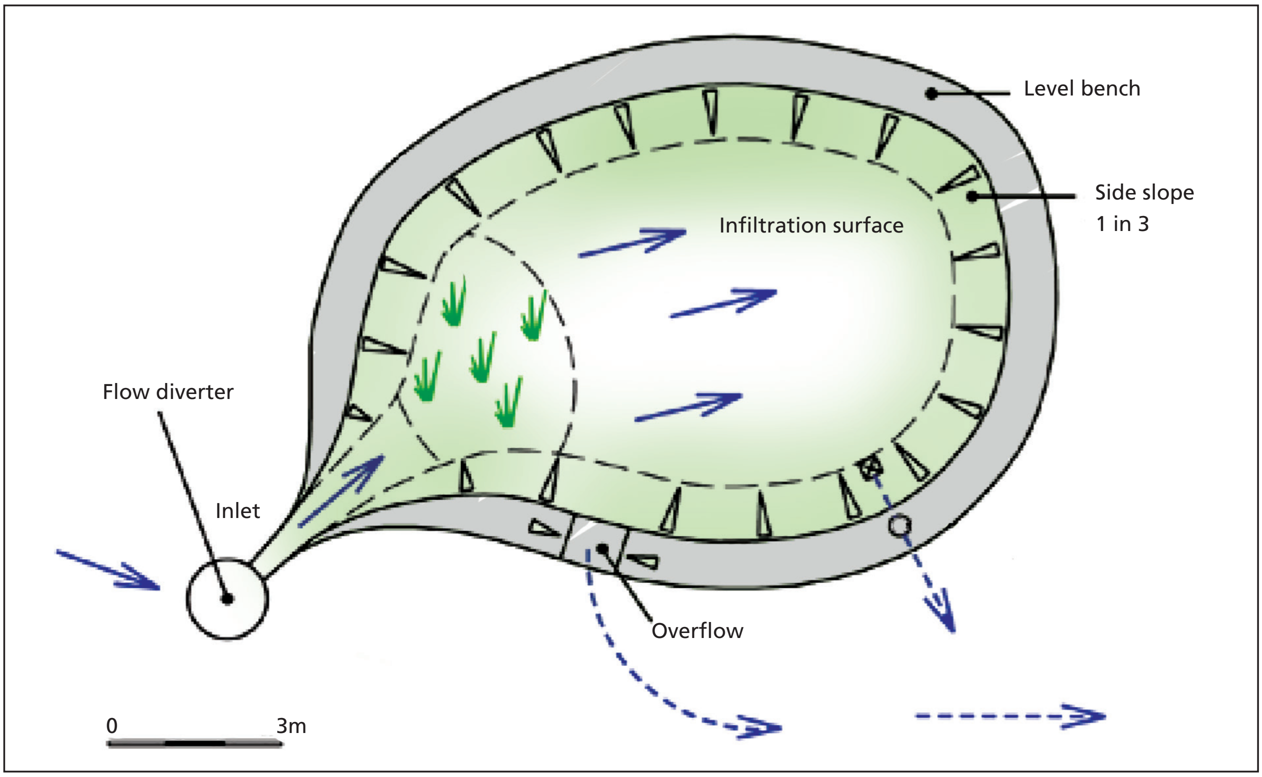
Source: CSE, 2016

Detention basins: Detention basins are vegetated depressions in the ground designed to store surface-water runoff and either allow it to soak into the ground or flow out at a controlled rate. Within development, these basins are usually small grassed areas, sometimes with a micro-pool or planted area at a low point where some standing water can accumulate.



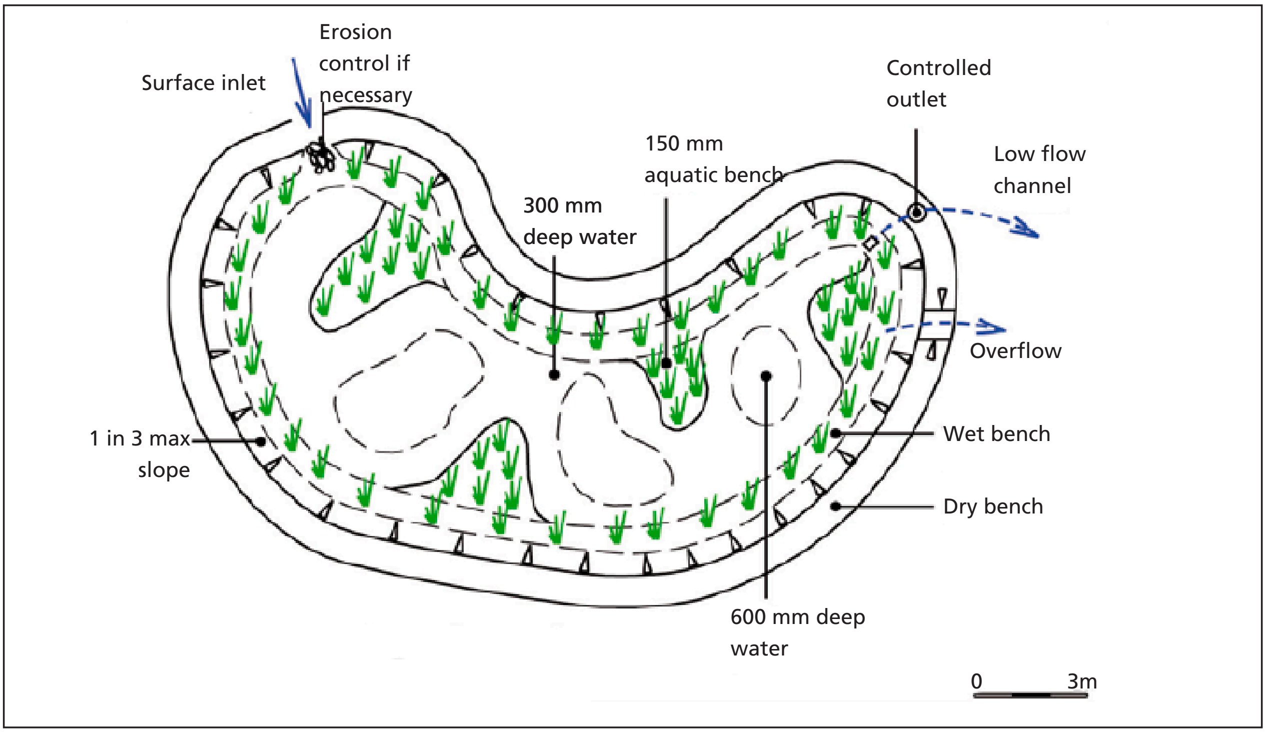
Source: CSE, 2016

Infiltration basins: The basins collect surface-water runoff from small areas and are usually off-line to prevent siltation.



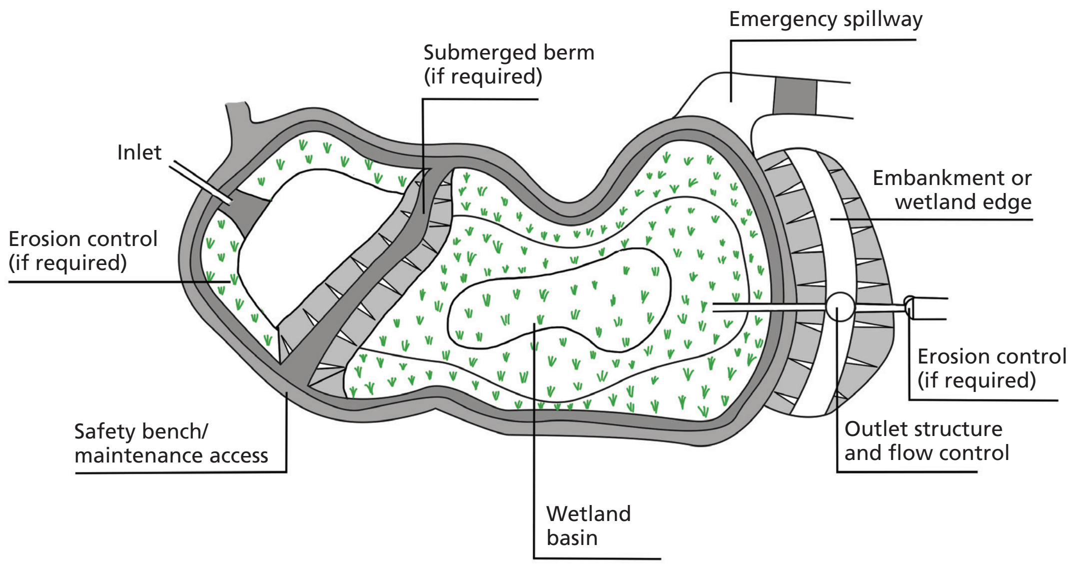
Source: CSE, 2016

Ponds: Ponds are depressions in the ground that contain a permanent or semi-permanent volume of water.



Source: CSE, 2016

Wetlands: Wetlands are shallow ponds with marshy areas, covered in aquatic vegetation. They retain sediments for an extended time and remove contaminants by facilitating adhesion to aquatic vegetation and aerobic decomposition



Source: CSE, 2016

Wastewater treatment: Pollution abatement in waterbodies

Over-exploitation, discharge of industrial effluents and domestic sewage, uncontrolled siltation and weed infestation are the main reasons of the destruction of the waterbodies and eventually destruction of safe water resource.[5] In urban areas, waterbodies like lakes and ponds often get contaminated because of mixing of wastewater from its catchment area. Since 62.5 per cent of urban areas in India get partial or no treatment of their wastewater, waterbodies and groundwater can get contaminated by sewage.[6]

Waterbodies play an important role in maintaining the natural hydrological cycle, offering numerous benefits to the ecology and healthy recreation. Thus, it is essential to design for pollution abatement of such waterbodies. This can be done by catchment treatment, protection of waterbodies by creating buffer zones and in-situ treatment (see *Table 11: Factors for designing effective natural wastewater treatment systems).* Some design options for pollution abatement of waterbodies are listed (see *Options and techniques to reduce pollution in waterbodies*).

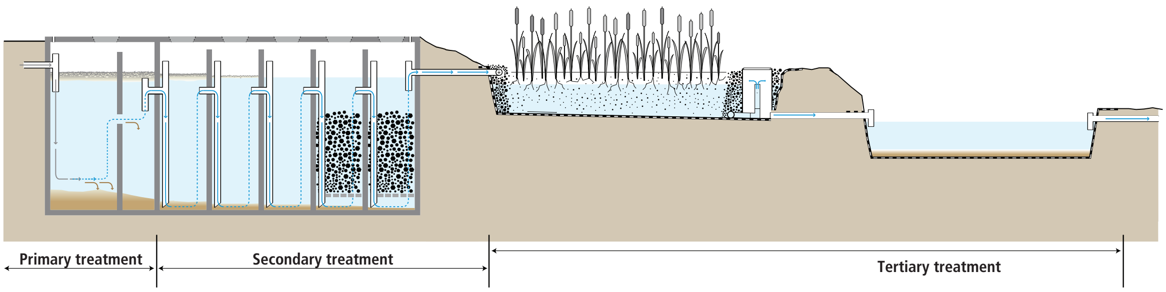
Table 11: Factors for designing effective natural wastewater treatment systems

Approach for pollution abatement in waterbodies	Scope of development
Catchment treatment	Catchment assessment and providing a natural treatment system to cater contamination of the catchment area
Protection	• Control the entry of water through inlets • Creation of buffer zone/treatment zone
In-situ treatment	Regular treatment of waterbodies as per the level of contamination

Source: CSE, 2016

Options and techniques to reduce pollution in waterbodies

Catchment treatment: Treatment of incoming contaminated water into a waterbody or treatment in stages in the catchment area using decentralized wastewater treatment.

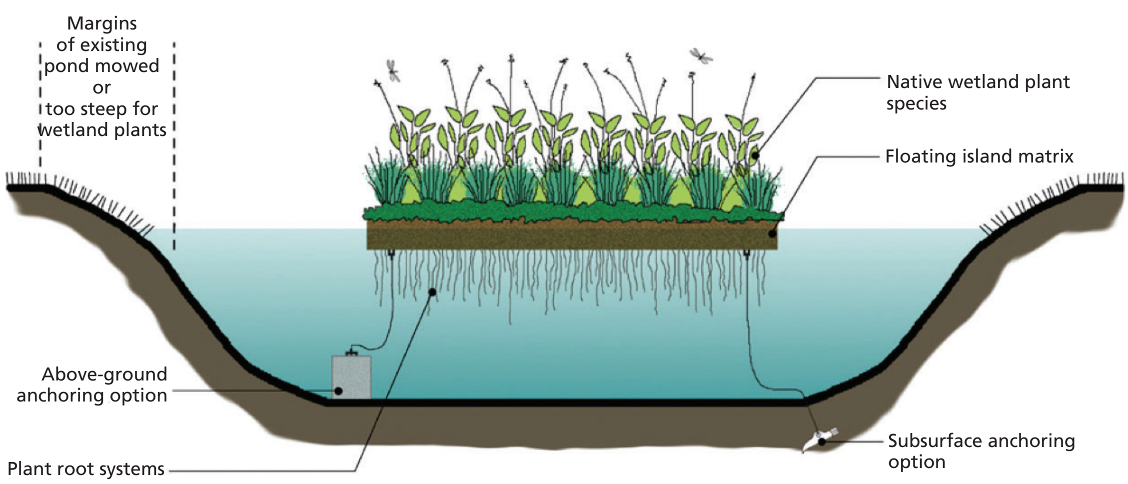


This approach is based on different natural treatment techniques put together in different combinations according to need. It includes:

- Primary treatment, which includes pre-treatment and sedimentation in settlement tank or septic tank
- Secondary anaerobic treatment in baffled reactors which provide for 60-90 per cent treatment (as designed)
- Tertiary treatment in reed bed system; and/or polishing in lined ponds

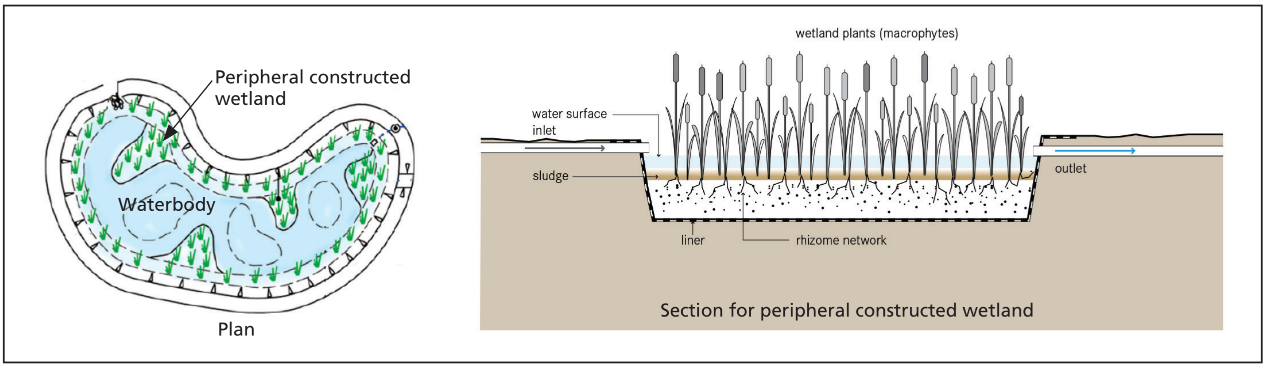
Source: CSE, 2016 and adapted from Tilley, E., et al, 2014, Compendium of Sanitation Systems and Technologies, 2nd Revised Edition, Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Switzerland

Floating wetlands (in-situ treatment): Creation of floating islands with wetland plants (rooted emergent macrophytes) that are grown on floating rafts/mats. This facilitates root-zone treatment and maintains or improves the water quality in the waterbody. The plant roots hang beneath the floating mat and provide a large surface area for bio-film growth which forms an important part of the treatment reactor.



Source: CSE, 2016 and http://texaswetlands.org/, as accessed on 3 May, 2017

Creation of buffer/treatment zone using constructed wetlands (floating/subsurface flow) on the periphery of the waterbody (protection): A peripheral wetland can be designed either as sub-surface flow type or a floating type. Depending on the design, the use of wetland plant species will vary and so will the capital and O&M cost



Source: CSE, 2016

Nualgi (in-situ treatment): In-situ treatment using phyto-remediation (use of micro/macro algae) fixes CO_2 for treatment, which removes nutrients and increases DO in water.

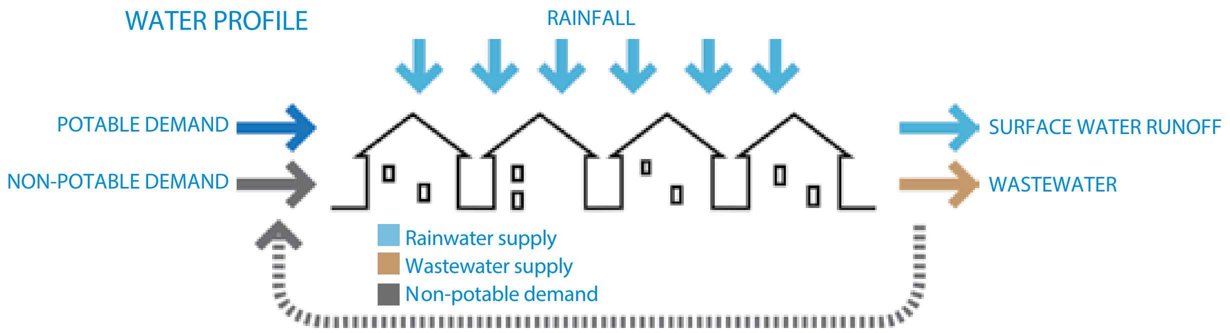
Bio-remediation (in-situ treatment): In-situ decomposition of organic matter in a waterbody using biological products. Depending on the type of product being used, the dosage, cost and frequency varies.

3.3 Water-sensitive designing (individual scale)

Water-sensitive aspects have conventionally received little or no attention in site/building designs and operation. This fact combined with wasteful water use patterns has resulted in water being used rather inefficiently in buildings.

Further, the available rainwater and wastewater at the site are not seen as resource but as liability (see *Figure 10: Ideal water cycle on an individual scale of an urban area*). The WSUDP approach includes guidelines on water-use efficiency relevant to most types of buildings, including residences, institutes, offices, hotels and restaurants.

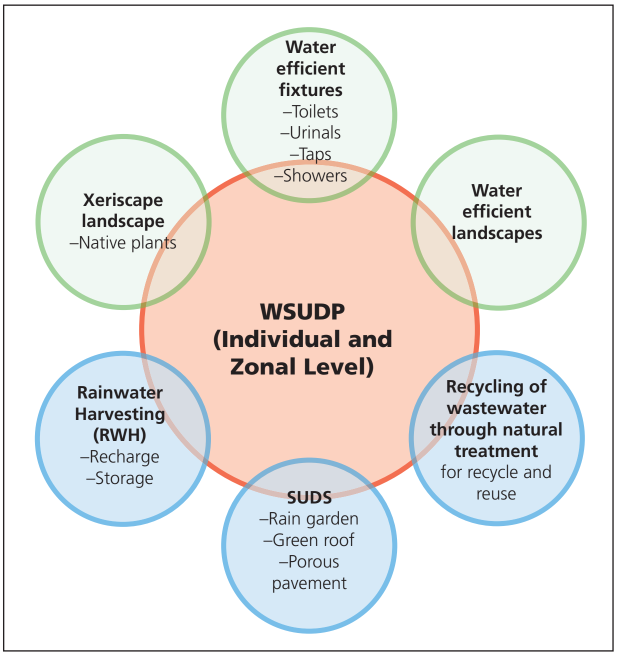
Figure 10: Ideal water cycle on an individual scale of an urban area



Source: Abbott, J. Davies, P. Simpkins, P. Morgan, C. Levin, D. Robinson, P. (2013). Creating water sensitive places, scoping the potential for water sensitive urban design in UK. London: CIRIA

A range of water-sensitive measures can be taken at a site to benefit the user. The use of water efficient fixtures and sustainable landscaping can help in conservation of water. The localized rainwater harvesting as well as recycle-reuse of wastewater can help in further conserving and managing the water resource. Apart from convenience, the simple measures can help the user take greater social and environmental responsibilities (see *Figure 11: Measures for water-sensitive approach on an individual scale*).

Figure 11: Measures for water-sensitive approach on an individual scale



Source: CSE, 2016

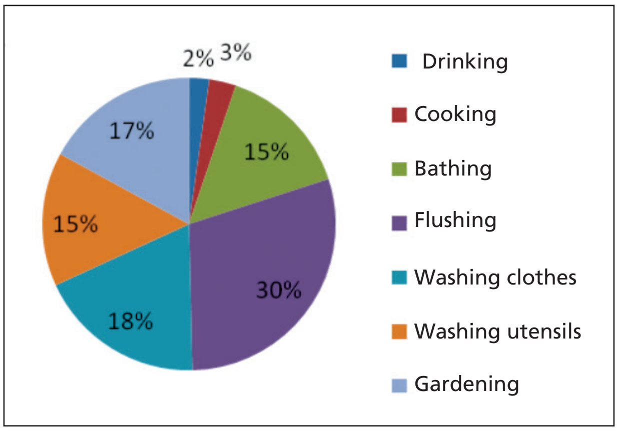
Water audit

Water audit is an on-site survey and assessment of water-using hardware, fixtures, equipment, landscaping and management practices to determine water-use efficiency and develop recommendations for improving it. It can be an effective on-site water-management tool. It identifies measures that can be taken to reduce water consumption and estimates water-saving potential. Comprehensive water audits give detailed profiles of the distribution system and water users, facilitating reliable and effective management of resources.[7]

Water conservation methods at individual scale

Water can be conserved at the site level from two uses. The first is water used for landscaping or irrigation, which does not demand high-quality water. It can be strategized by maximum use of native vegetation and trees. The second is in the demand for water in buildings. Water-efficient fixtures can reduce water consumption by 36 per cent.[8]

Figure 12: Water consumption break up per person



Source: CPHEEO, G. (1999). Manual on water supply and treatment.

Additionally, nature and pattern of usage need to be considered. For example, for a building to promote water-efficiency and conservation measures, it is required to study water usage in buildings to recommend areas of potential improvement. At residential sites, toilets and bathrooms are seen to be the biggest water consumers, with flushes, taps and showers using over 60–70 per cent of total water used (see *Figure 12: Water consumption break up per person*).

Water-efficient fixtures

Water-efficient fixtures are designed to use less water while maintaining the same level of performance as conventional water fixtures. Reducing water consumption by using water-efficient fixtures is a major step towards sustainable water management. Use of efficient plumbing fixtures, sensors, auto valves and pressure-reducing devices result in significant reduction in water consumption[9] (see *Table 12: Water saved by using water-efficient fixtures*).

Table 12: Water saved by using water-efficient fixtures

Fixture	Water use in standard fixtures	Water-efficient fixtures	Estimated water savings
Toilet	Single flush toilet users 10–13 litres/flush	Dual flush toilet in 3/6 and 2/4 litre models	4–11 litres/flush
Urinals	4 litres; 10–13 litres/flush	Sensor operated adjustable flush	2.2–10 litres/flush
Taps	10–18 litres/minute depending on pressure	Sensor taps	5.5–15.5 litres/minute
Showers	10–15 litres/minute	Flow restrictors	4-20 litres/minute

Source: Rohilla, S. Dasgupta, S. (2011). Roadmap for Rating System for Water Efficient Fixtures. New Delhi: CSE

Water-efficient landscapes

Water-efficient landscaping—i.e. growing native species, efficient irrigation systems and limiting lawn areas—is practised to minimize water usage. Appropriate planting and efficient irrigation systems can reduce water used in irrigation by 50–70 per cent and overall water consumption by 25 per cent. Further, green area of a site helps in reduction of storm-water runoff.[10]

A well-designed landscape is possible in two ways:
- Planting native vegetation/flora and xeriscaping
- Using efficient irrigation equipment

The term xeriscape, i.e. water-conserving garden, is derived from the Greek *xeros*, meaning dry, and ‘landscape’. A xeriscape landscape grows native species to minimize water use and enable water to be channelled to plants that need more water. Xeriscape landscaping is an efficient way to reduce water consumption through creative landscaping. It involves planting native plants and those that can survive with little or no supplemental watering. Xeriscaping uses natural features of the local environment, harnessing greater adaptability. Native species and xeriscape vegetation give the twin advantages of water efficiency and ease of maintenance.[11]

Water-efficient irrigation systems

Water-efficient irrigation systems help extend water availability. Conventional irrigation systems can result in over-irrigating plants, leading to flooding and high runoff that results in soil erosion. Efficient irrigation equipments reduce the water requirements for plants.[12]

Efficient water and wastewater management: On-site techniques

With water-efficient management, the major part of annual water demand can be met through RWH and recycling/reuse of treated wastewater.

Designing a rainwater harvesting system

RWH systems use the principle of conserving rainwater ‘where it falls’. Rainwater can be collected from the catchment areas (roofs, paved and unpaved) of a site. The two ways of harvesting rainwater include:

(1) Storing it in receptacles and
(2) Recharging the aquifer (see *Table 13: Rainwater harvesting techniques*).

Total volume of harvested water = Area x runoff coefficient x rainfall

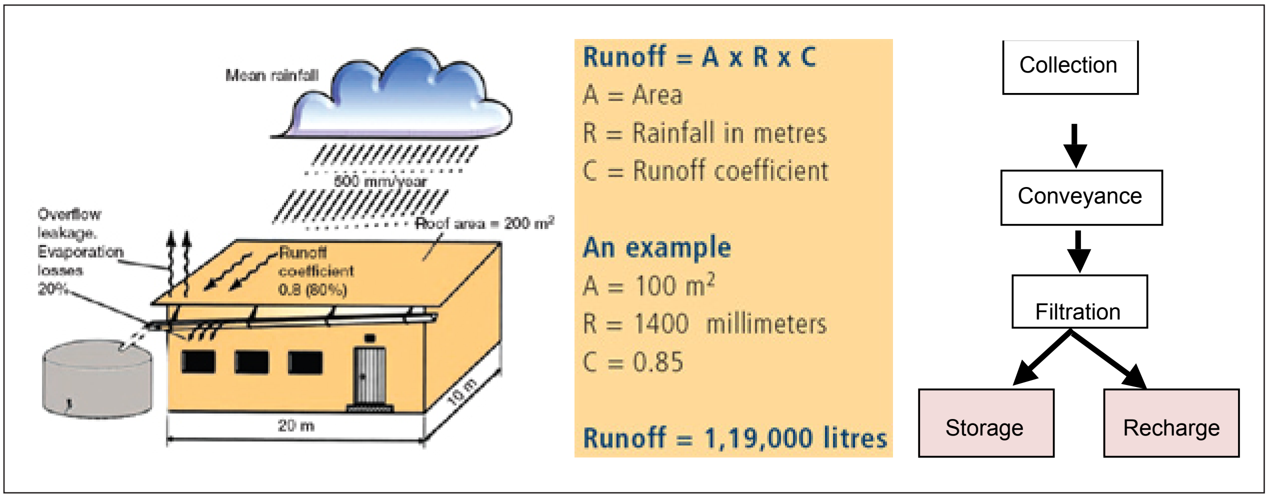
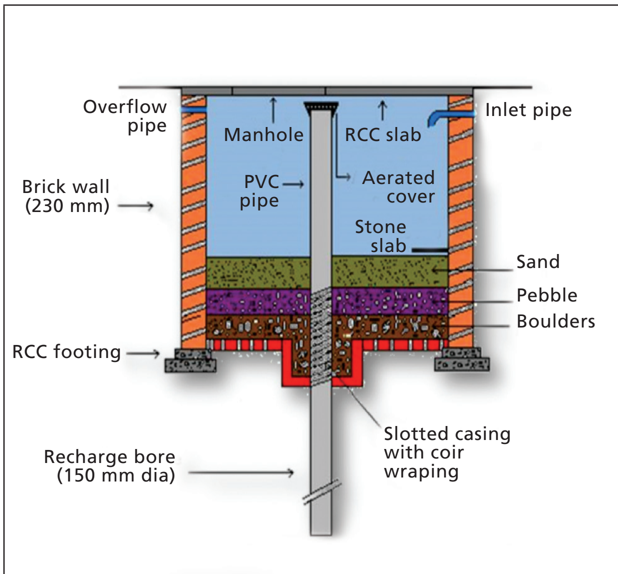


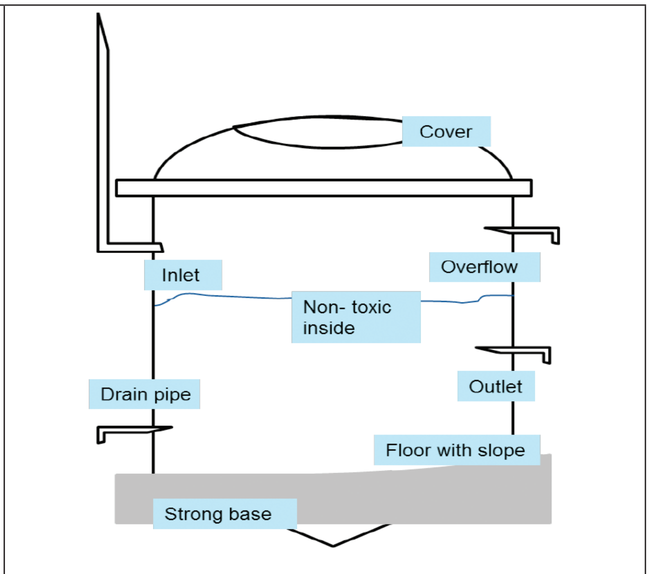
Table 13: Rainwater harvesting techniques

Recharge structures	Storage tanks
• Recharge pits • Recharge pits with bore • Recharge well • Recharge trenches • Recharging through abandoned bore wells or tube wells • Recharging: using bore wells and dug wells	• Polyethylene • Polypropylene and similar synthetic material (PVC tanks) • Brick masonry • Reinforced cement concrete (RCC tank) • Ferro-cement • Galvanized iron (GI tanks)

Source: CSE, 2016



Typical cross section of recharge structure

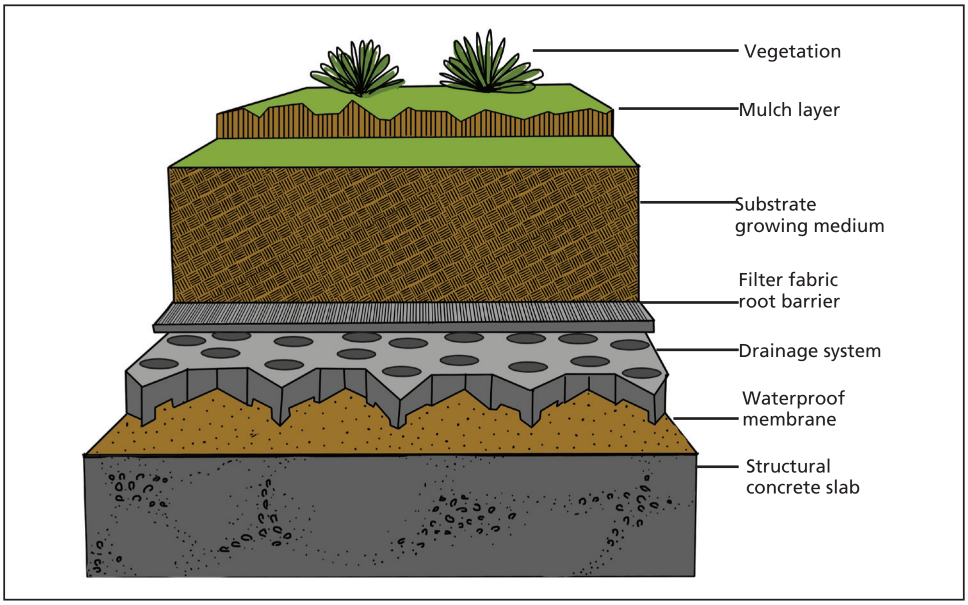


Typical storage structure

Source: Kavarana, G. Sengupta, S. (2013). Catch water where it falls. New Delhi: CSE.

Other on-site storm-water management landscape feature

Green roofs: Green roofs are multi-layered systems comprising a vegetation cover or landscaping above a structural slab of open terrace/roof. Their aim is to intercept and retain precipitation which then results in fewer surface run-offs



Source: CSE, 2016

On-site wastewater management

The choice of technology for a specific site depends on several factors, such as wastewater quantity generated, type of reuse or site for disposal of wastewater (this determines the level of treatment required), land available, availability of skilled operating manpower and budget.

For local reuse, type of use becomes the main criteria to decide on level of treatment required. DWWT and local reuse at the community, institutional and individual scales can help achieve the twin objectives of equity and sustainability. At the site scale, systems that are least dependent on factors such as electricity supply and skilled labour, and require least budgetary investment for its capital as well as O&M are favourable.

The following are techniques that can be opted for treatment on a small scale depending upon feasibility at the site (see *Table 14: Decentralized wastewater treatment technologies*). To design DWWTs, a detailed checklist is appended (see *Appendix C.2*).

Table 14: Decentralized wastewater treatment technologies

Treatment method	Treatment capacity (feasible)	Reuse
Bio sanitizer/eco chip	100 mg of eco chip can treat 1 KLD	In situ treatment of water bodies, horticulture
Soil biotechnology	5 KLD–3.3 MLD	Horticulture, cooling systems
Soil-scape filter	1–250 KLD	Horticulture
DWWTs	Should be more than 1 KLD, but plants bigger than 1 MLD are not feasible as they would need extensive land	Horticulture, mopping floors, cooling towers and flushing
Eco sanitation Zero-discharge toilets	Individual and community toilets together depending upon the number of users	Flushing, horticulture, composting
Fixed film bio-filter technology	0.5 KLD–1 MLD	Horticulture, car washing
Phytorid	0.5 KLD–1MLD	Horticulture

Source: CSE, 2016

Designing a decentralized wastewater treatment system for local reuse

Objective of DWWTs

- Abatement of pollution in the catchment area
- Water sensitive planning—reducing water demand by reuse/recycle
- Lake management and revival

Data collection

- Volume of wastewater (depends upon population, water consumption pattern)
- Quality of wastewater depends on type of water consumption

Site feasibility

- Analysis of site plan
- Environmental conditions (temperature, groundwater table)
- Building codes and by-law—distance from water well, building foundation etc.

Deciding level of treatment required

- The required treated water quality depends on type of reuse/ discharge

Source: CSE, 2016

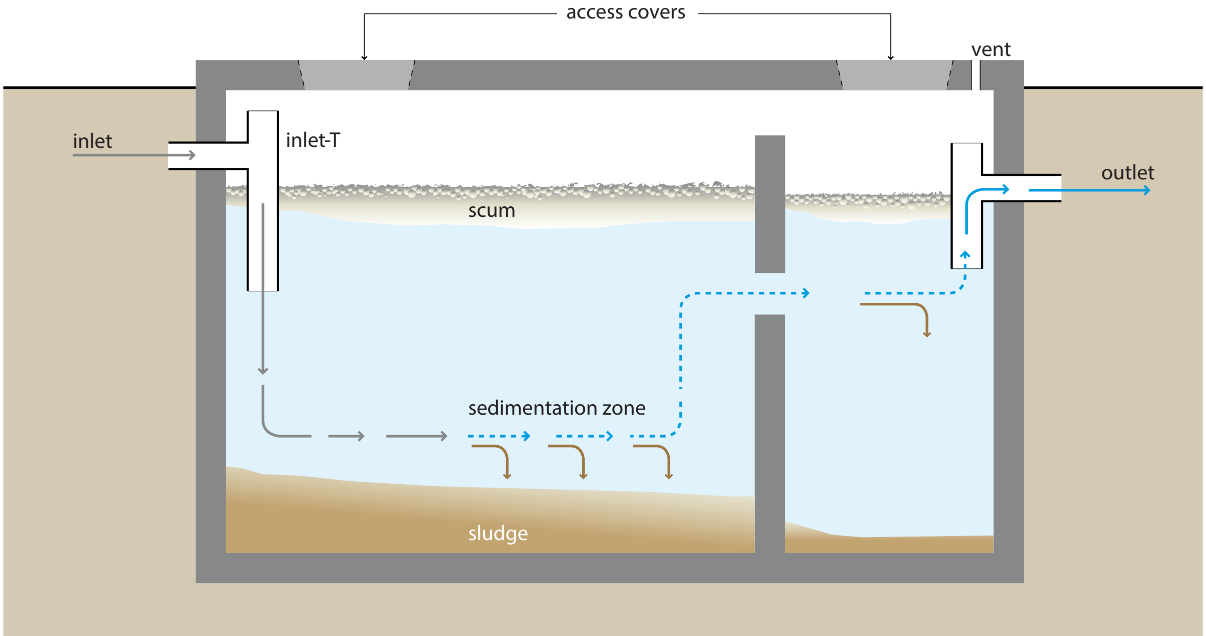
Area requirement

Settler

Surface area requirement:
0.5 sq. m/cum (generally can be constructed underground and incorporated into existing open paved areas)

Crucial design specification and rule of thumb:

- Provides primary treatment—removal of suspended solids
- Up to 20–30 per cent of biological oxygen demand (BOD) and chemical oxygen demand (COD) removal
- Can be designed with two or three chambers where the first chamber has more length of flow than the others
- Length : Breadth ratio is maintained at 3:1
- Depth to be maintained at 1–2.5 m
- Surface loading rate should not exceed 0.6 cum/sq. m of wastewater peak hour flow
- Optimum retention time 2–3 hours with the peak hour flow



Source: CSE, 2016 and Tilley, E., et al, 2014, Compendium of Sanitation Systems and Technologies, 2nd Revised Edition, Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Switzerland

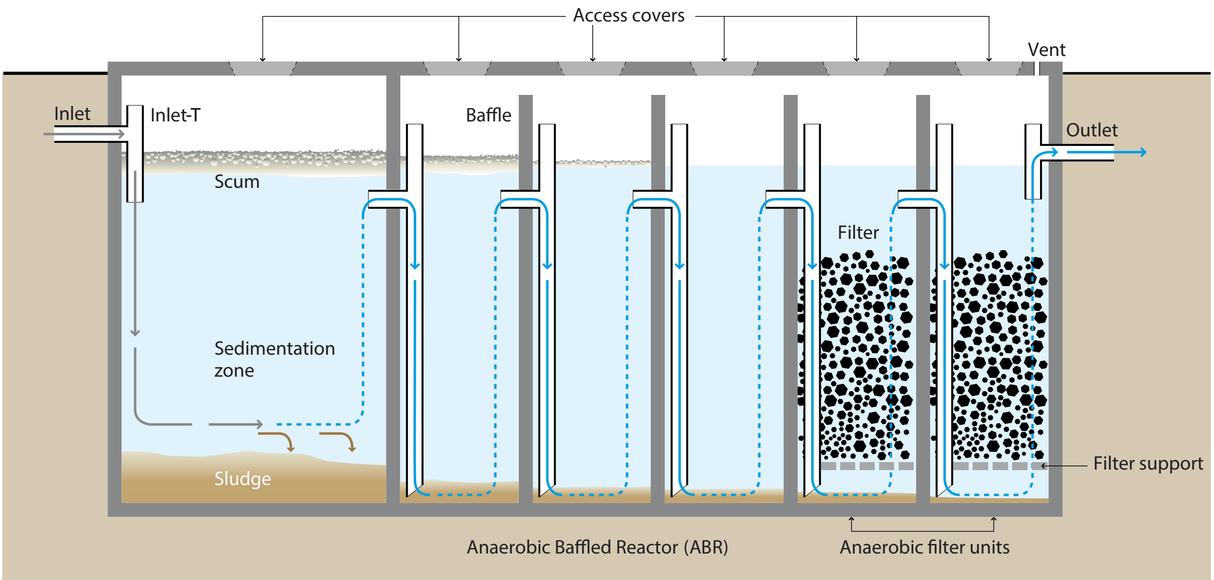
Anaerobic baffled reactor

Surface area requirement:

1 sq. m/cum (generally can be constructed underground incorporated into existing open paved area)

Crucial design specification and rule of thumb:

- Provides secondary treatment—anaerobic bio-degradation, causing about 60–90 per cent removal of BOD and COD
- Depth to be maintained at 1–2 m
- Upflow velocity to be maintained between 1.2–1.5 m/hr
- Optimum retention time—21–24 hrs
- It is desirable to have surface organic load below 4 kg BOD/cum per day



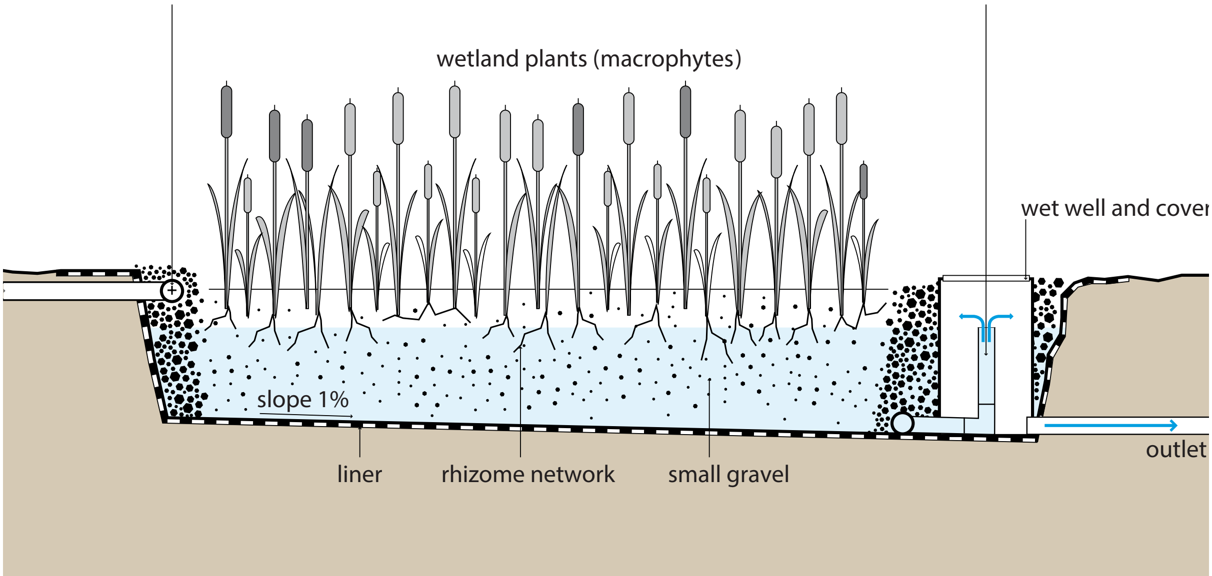
Source: CSE, 2016 and adapted from Tilley, E., et al, 2014, Compendium of Sanitation Systems and Technologies, 2nd Revised Edition, Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Switzerland

Horizontal flow planted filter bed

Surface area requirement:
4 sq. m/ cum (generally open to air structure incorporated into green spaces at the site)

Crucial design specification and rule of thumb:

- Provides both secondary and tertiary treatment depending upon the design—removes excess nitrates and phosphates and can also be designed for further bio-degradation (BOD and COD removal)
- Organic loading: 10–30 g BOD/ sq. m/day; Hydraulic loading: 40–100 litre/sq. m/day
- Media: Crushed stone of 60–80 mm in diameter are preferred
- Plants: Locally available wetland plants (emergent macrophytes), e.g. *Typha*, *Scirpus*



Polishing pond

Surface area requirement:
1.2 sq. m/cum (generally open to air structure incorporated into green spaces at the site)

Crucial design specification and rule of thumb:

- Provides tertiary treatment—removal of pathogens and odour
- Exposes treated wastewater to atmosphere and sunlight with retention time of 1–3 days
- Depth shouldn't be more than 1–1.5 m

Source: CSE, 2016 and adapted from Tilley, E., et al, 2014, Compendium of Sanitation Systems and Technologies, 2nd Revised Edition, Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Switzerland

4. Implementation of WSUDP

Several aspects are involved in implementing WSUDP, namely land-use type, O&M, costing, stakeholder participation, social and ecological impact, and its successful implementation requires careful consideration of what it means in practice.[1] Including all the aspects increases an understanding of issues and challenges, generates more data, helps determine priorities, increases support for remediation programmes and enhances the likelihood of success of any project.

Application of WSUDP measures on various land-use types

In the drive to optimize the use of land, little connection remains between the land use dedicated in the master plans and the actual use of land. Many land uses dedicated in the master plans address the supply side without actually providing guidance on the mobilization of the land. Urban lands today are largely seen as real estate cash flows and a reference to the opportunities for creating social and physical infrastructure is rare.[2]

The URDPFI guidelines provides ground rules for the percentage of maximum allowable ground coverage for each land-use activity in India. The same data is used to find out potential open areas that can be used for implementing strategy for WSUDP. According to the guidelines (see *Figure 13: Ratio of built-up to open area in different land uses*), the average built-up area for an urban area is 24 per cent while for an open space it is 76 per cent. The standards and guidelines provide enough open areas to design the projects.

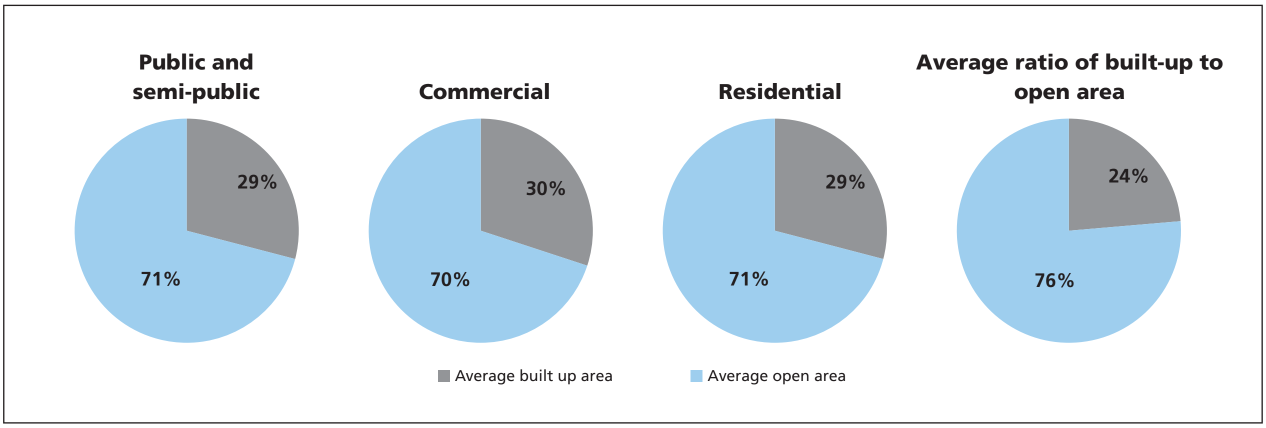
Integration of different WSUDP measures in different scales

Table 15: Application of WSUDP measures on various scales shows the integration of different WSUDP measures that can be implemented on various scales.

WSUDP interventions at various scale depends on following factors:

- Site conditions and catchment characteristics (e.g. location, geography)
- Land-use type (e.g. residential, commercial, industrial)
- Water use and demand
- Water sources available and local climate (e.g. rainfall seasonality)

Figure 13: Ratio of built-up to open area in different land uses



Source: Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines (2014), Ministry of Urban Development.

Table 15: Application of WSUDP measures on various scales

WSDP measures		Single detached dwellings	Commercial and industrial development	Medium- and high-density residential development	Public open space	Transport infrastructure	Waterbodies and surroundings
Water conservation	Water-efficient fittings and appliances	✓	✓	✓			
	Sustainable landscaping	✓	✓	✓	✓	✓	✓
On-site water management	Rainwater harvesting	✓	✓	✓			
	Wastewater recycle and reuse	✓	✓	✓			✓
Storm-water management	Filter strips	✓	✓	✓	✓	✓	
	Swales		✓	✓	✓	✓	✓
	Bio-retention areas and rain gardens		✓	✓	✓	✓	✓
	Filter drains and trenches	✓	✓	✓	✓	✓	
	Permeable pavements	✓	✓	✓	✓	✓	
	Detention basins		✓	✓	✓	✓	
	Infiltration basins		✓	✓	✓	✓	
	Ponds		✓	✓	✓		✓

Source: WBM, B. (2009). Evaluating options for water sensitive urban design–a national guide. Joint Steering Committee for Water Sensitive Cities (JSCWSC)

- On-site catchment area (e.g. roof and surface)
- Urban landscape design (e.g. architectural and landscape)

4.1 Operation and maintenance

Effective O&M of a project is a critical component of any WSUDP strategy. The task of O&M has to be performed as a preventive approach in order to attain sustainability of the design. The O&M of a system is the continuous process of monitoring individual components of a system that are functioning properly to the desired specifications. Routine maintenance and proper upkeep are directly related to efficiency of the systems. Incorrect or deficient maintenance results in lower water quality and increased health risks. Each system is unique and has its own subtle variations in performance and functionality.[3]

WSUDP interventions require both proactive and reactive maintenance to ensure long-term sustainability of the system. Proactive maintenance refers to regular scheduled maintenance tasks, whereas reactive maintenance is required occasionally to address unscheduled maintenance issues. If a system is not functioning as intended, then rectification may be required to restore it to its desired function.

Proactive maintenance is a set of scheduled tasks to ensure that the WSUDP system is operating as designed. Proactive maintenance involves regular inspections of the WSUDP systems, scheduled maintenance tasks for issues that are known to require regular attention (e.g. litter removal, weed control) and responsive maintenance tasks following inspections for issues that require irregular attention (e.g. sediment removal, mulching and scour management). Proactive maintenance in the first two years after the establishment period (construction and planting phases) are the most intensive and important to the long-term success of the treatment system. Proactive maintenance is a cost-effective means of reducing the long-term costs associated with operating the assets.

Reactive maintenance is undertaken when a problem or fault is identified that is beyond the scope of proactive maintenance. Reactive maintenance may occur following a complaint about the WSUDP system (e.g. excessive odours or litter). Reactive maintenance often requires a swift response, and may involve specialist equipment or skills.[4]

Maintenance activities specific to each WSUDP systems type are detailed in the inspection and maintenance schedules and checklists provided (*Appendices D.1 and D.2*). The frequency of scheduled maintenance depends on the asset type and issue being managed. The checklists provided should be used as a minimum guide to schedule maintenance tasks and should be amended to suit different system designs and maintenance requirements. WSUDP systems should also be inspected at least twice a year during or immediately after a significant rainfall event.

4.2 Stakeholders' analysis

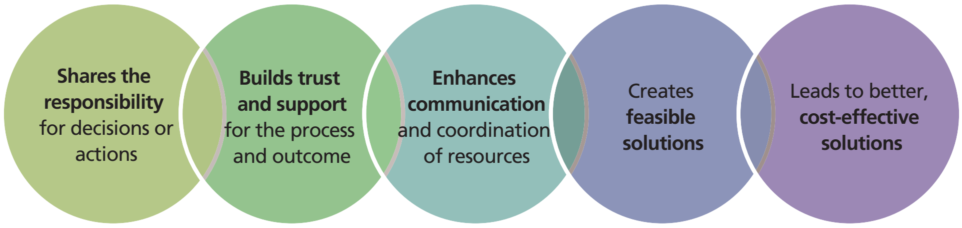
Stakeholder involvement is important for the success of any WSUDP intervention. Water management occurs within a highly complex and multi-constrained context (including social, ecological, political and economic aspects) and requires a clear recognition of how the various stakeholders might work collaboratively to address the range of water security concerns that the respective country faces.[5]

Managing the urban water cycle in a holistic manner is not possible without engaging all those who are either using the water or who are responsible for taking care of its individual elements via policymaking, legislation, regulation, construction, abstraction, water treatment, etc. The bigger the city, the wider is the array of institutions, interest groups and user associations that are linked to the urban water cycle. For the success of an integrated approach it is important that all the key stakeholders are taken on board. Collaboration needs to be planned, with support from relevant stakeholders, those who will make decisions, those affected by them and those who can stop the process if they disagree (see *Figure 14: Benefits of engaging stakeholders in WSUDP projects*).

To attain a sustainable water management system it is important that the involvement of all the relevant stakeholders with different roles and responsibilities starts at the planning stage. The step-by-step process of planning and implementation of various WSUDP interventions in consultation with stakeholders is as shown in *Figure 15: Stakeholder participation in the planning and implementation process*.

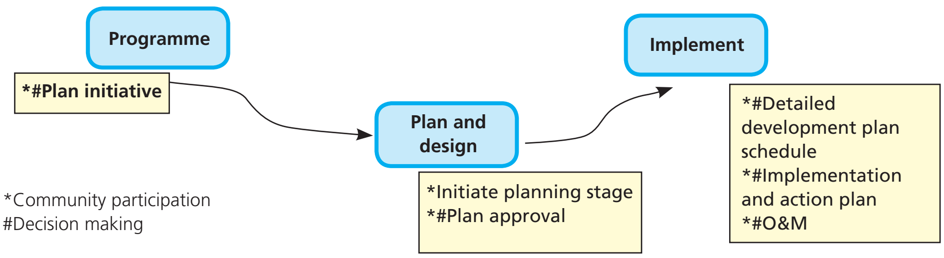
In WSUDP approach, a stakeholder is a person (or group) responsible for making or implementing a management action, who would be significantly affected by the action, or who can aid or prevent its implementation. According to the 74th Constitutional Amendment, ULBs are considered the responsible

Figure 14: Benefits of engaging stakeholders in WSUDP projects



Source: Adapted from Tech, T. (2013). Engaging Stakeholders in your Watershed. Washington, DC: United States Environmental Protection Agency.

Figure 15: Stakeholder participation in the planning and implementation process



Source: Adapted from Municipality, N.M.B. (2007). Sustainable Community Planning Guide. Nelson Mandela Bay Municipality: Port Elizabeth.

stakeholders for the implementation of WSUDP measures—these comprise municipal corporations, municipal councils and nagar panchayat.

The public, as end-beneficiaries and consumers, create the demand for a high-quality water supply, and it is for them that the environment is conserved both now and in the future. Developers respond to the demand for new housing and the development plans that drive the requirement for new water supply, drainage and wastewater infrastructure. The water supply and sewerage providers have the responsibility to provide the infrastructure via sustainable and environmentally acceptable routes. Environmental agencies have a duty to protect and improve the environment and the power to regulate abstractions from and discharge to controlled waters. They also undertake consultation and provide guidance on environmental aspects of the land-use planning process.

Thus the major stakeholder groups, based on their level of influence on WSUDP adoption, can be classified as:

(a) Direct beneficiaries: Those who directly influence the decision-making process or are directly impacted by it
(b) In-direct beneficiaries: Those who can influence the decision-making process but may not directly be involved in it. They benefit from it, but their influence on decision making is via indirect or complex influence channels.

Table 16: Key stakeholders for WSUDP implementation gives a breakup of the various key stakeholders that should be considered in the development/implementation of WSUDP projects.

Direct beneficiaries

WSUDP direct beneficiaries include local governments, state authorities, academicians, technical experts and residents. Within this group the role and level of influence of residents will vary with the type of WSUDP feature adopted. The implementation of some features such as storm-water intervention in public land may occur with limited awareness of residents, whilst the retrofit installation of a rain garden next to a private property may require the cooperation of residents.

Local government is perceived by other stakeholder groups to have considerable influence in the decision-making process for WSUDP implementation. Their influence is due to their control of the development approvals process and the DPRs.

The direct beneficiaries also include consultants and independent research organizations that directly influence WSUDP implementation through contracts with developers and local government to deliver concepts and engineering designs. However, their actual influence on successful WSUDP uptake is dependent on their expertise and their ability to deliver a WSUDP system that fulfils the development plan requirements.[6]

Universities and professional organizations provide expertise on all aspects of WSUDP. They can build capacity for WSUDP approach among students and professionals, and advocate for improved practices for WSUDP implementation. Research agencies and universities also contribute by addressing WSUDP research gaps and improving technical guidelines. These institutions are perceived as independent so they can act as trusted advisors to other stakeholder groups.

Table 16: Key stakeholders for WSUDP implementation

Direct beneficiaries	**Planners**
	Urban planner Environmental planner Transport planner Infrastructure planner
	Architects
	Landscape architect Building architect
	Engineers
	Environmental engineer Civil engineer
	Users
	Residents/community
	Researchers
	Academician/researchers
	Other technical experts
	Geographer Hydrologist Geologist
	Consultants
In-direct beneficiaries	Environmental groups
	NGOs
	Local residents

Source: CSE, 2016

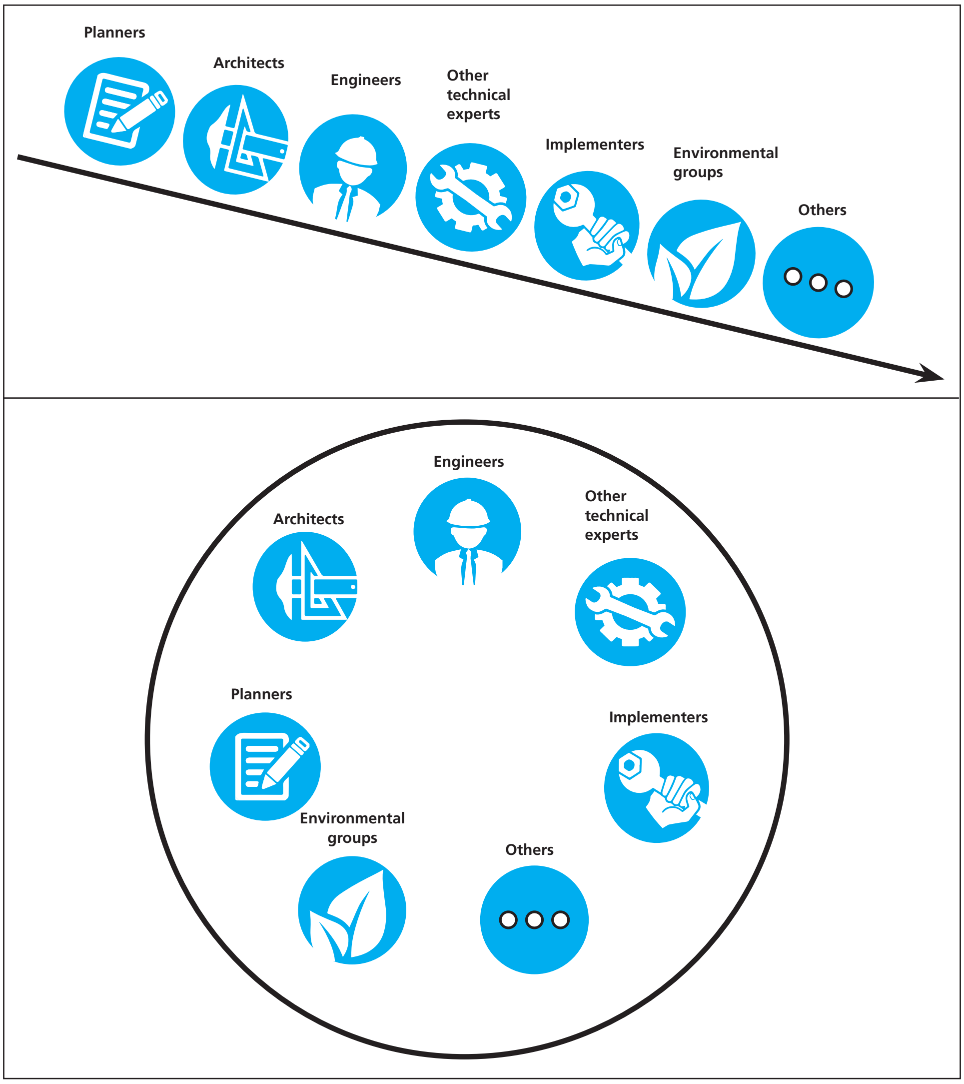
Indirect beneficiaries

These stakeholders include practitioners that can influence WSUDP implementation, but who may not be directly linked to the decision-making process. For example, environmental groups may focus on the preservation of local waterbodies, which places a greater emphasis on the need for source control of storm-water quality. Local residents may object to the construction of a rain garden if they dislike the feature aesthetics and exert pressure on their local authorities to stop the implementation.

Collaborating with different stakeholder

Individual stakeholders such as planners, architects and engineers can undertake several steps towards meeting the WSUDP objectives. However the overall process of WSUDP, including management from different sectors (water conservation, onsite water management and storm-water management), is more effectively implemented in an interactive or cyclical way among various stakeholders and not in the conventional linear manner that causes lack of coordination among various stakeholders. *Figure 16: Conventional and integrated stakeholder approach* shows that as the emphasis is on an integrated approach, WSUDP can be implemented most effectively when it is supported by an interdisciplinary team working together throughout the plan and design process.

Figure 16: Conventional and integrated stakeholder approach



Source: CSE, 2016

4.3 Economics of WSUDP

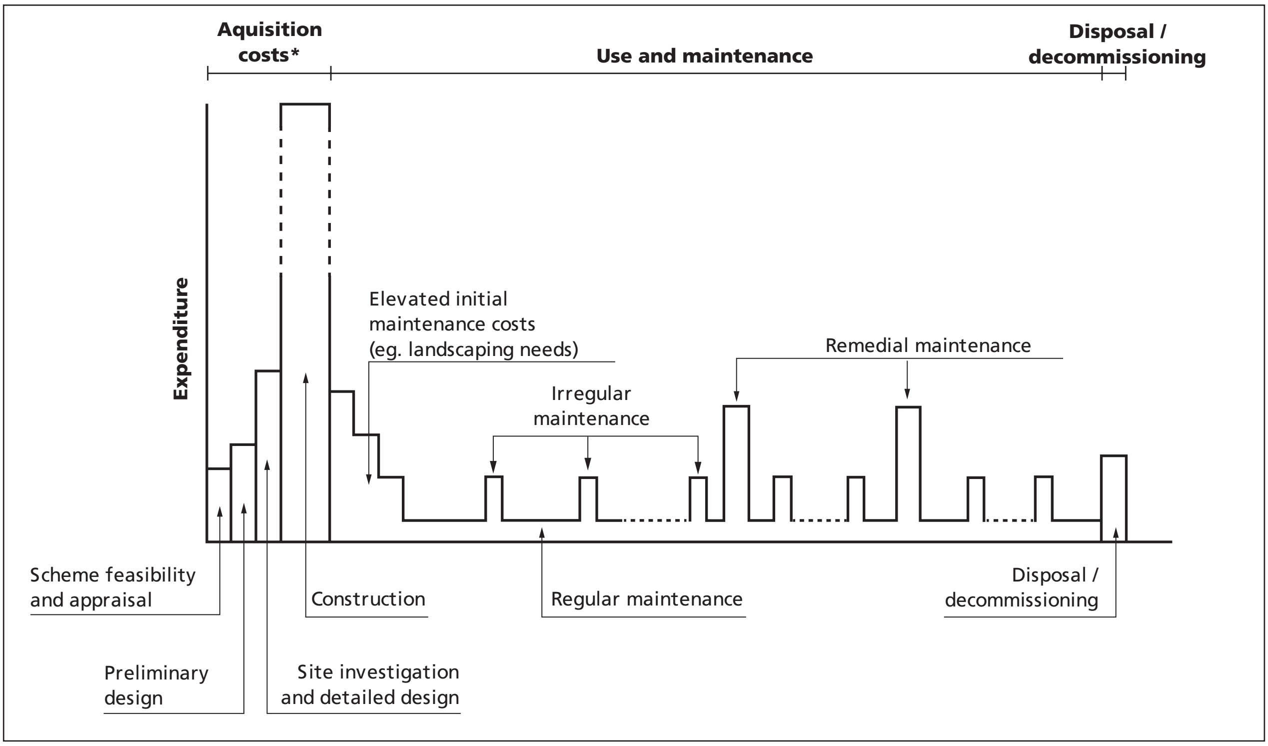
The cost of implementing a WSUDP measures can be weighed against the various benefits that they provide—although many of these benefits are likely to accrue to society rather than the developer or implementing body (see *Figure 17: Profile of conceptual WSUDP expenditure*). In addition to capital costs, WSUDP may require routine monitoring and maintenance. A long-term operating finance stream would therefore be needed.

Factors affecting costs

The actual costs of WSUDP measures and therefore WSUDP schemes are dependent upon several factors many of which are site specific. Generalization about costs can therefore be problematic and includes a high level of uncertainty. The following factors affect the costs of SUDS solutions:

- Soil type—Excavation costs are higher on rocky soils and the opportunity to implement infiltration solutions varies

Figure 17: Profile of conceptual WSUDP expenditure



Source: Ballard, B.W. et al. (2007): The SUDS manual, CIRIA C697, London

- Groundwater vulnerability—In vulnerable areas some WSUDP measures will need impermeable liners to prevent infiltration which will increase costs
- Design criteria—More stringent requirements for run-off control will lead to larger and more WSUDP measures in the system
- Design features—Extensive planting is more expensive than WSUDP measures that are allowed to colonize naturally
- Access issues and space requirements—Some measures take up land that would otherwise be used for development
- Location—Regional variations in labour and material costs, topography and soil conditions, including permeability and local rainfall characteristics, affect design criteria
- System size—Larger schemes offer the opportunity for economies of scale to be realized
- New build or retrofit—The cost of installing a WSUDP solution in an existing development is different from the cost of installing it as part of a new development.

Broadly, collection of all the existing data concerning site conditions, design, implementation and O&M activities comprise the measure heads for costing of an WSUDP system. The budget is divided into three major heads on the previous successful projects implemented by CSE (see *Table 17: Allocation of budget for WSUDP intervention*).

To get an idea about the major investment in the implementation of WSUDP structures, the implementation cost of DWWT system and setting RWH system is provided (see *Table 18: Schedule rates for RWH and DWWT components*).

Table 17: Allocation of budget for WSUDP intervention

Activity	Activity components	Allocation of budget
Collection of data and design (survey and analysis)	• Meteorological parameters • Site plan and catchment area • Drainage pattern (natural/artificial) • Catchment mapping (for big projects) • Survey: location, geology/soil, slopes, drainage line and sewage discharge arrangements • Water demand assessment and storage potential planning • Design of the structures	5%
Implementation (civil work)	• Type of structure (readymade, constructed) • Filter media • Interconnecting pipes • Gutter	80%
O&M	• Cleaning/replacing filter media (sand, gravels, pebbles, charcoal, jute choir etc.) • Removing silt • Repairing leaking tanks/cracks at catchment and tanks • Conducting water quality tests (total dissolved solids, total suspended solids, minerals, pathogens) • Paying salary to caretaker/operator	15%

Source: CSE, 2016

Table 18: Schedule rates for RWH and DWWT components

Part of rainwater harvesting system	Per unit	Cost (Rs) in 2016
Polyethylene water storage tank—circular and rectangular tank	litre	7.25
Gravel 5 mm to 10 mm	cum	800.00
Gravel 1.5 mm to 2 mm	cum	800.00
Gravel 3 mm to 6 mm	cum	800.00
Polyvinyl chloride (PVC) slotted pipe 150 mm diameter	metre	450.00
PVC slotted pipe 200 mm diameter	metre	700.00
Painting (two or more coats) on (with black anti-corrosive bitumastic paint) 100 mm diameter pipes	metre	35.85
Painting (two or more coats) on (with black anti-corrosive bitumastic paint) 150 mm diameter pipes	metre	53.50
Chlorinated polyvinyl chloride (CPVC) pipe 100 mm inner diameter	metre	985.00
CPVC pipe 150 mm inner diameter	metre	1462.00
PVC slotted pipe 100 mm diameter as per IS:12818	metre	380.00
Vent pipe (socketed soil, waste) 100 mm diameter	1.80 m long	1196.00
Carriage of stone aggregate below 40 mm nominal size	cum	103.77

Source: Central Public Works Department, 2016. Delhi schedule of rates, Government of India

The financial impact will be savings associated with a reduced need for conventional water supply (may include the avoided cost of using municipal water associated with water supply infrastructure). It will also cause changes to annual property rates of nearby properties due to changes in their value (including the impact on the rate of sales for houses on new estates). Further, there are huge social and ecological impacts of WSUDP on surrounding areas, covered in details in next section (see *Section 4.4 Social and ecological impact by WSUDP approach*).

Economic benefits from RWH systems can be quantified in the following example:

- Construction cost of rainwater harvesting systems = Rs 300,000
- Annual expense for purchase of water from tankers = Rs 60,000
- Annual expense from municipal water supply = Rs 24,000
- Total annual water bill = Rs 84,000
- Sourcing water supply from water tanker is halted
- Annual savings in water bill = Rs 60,000
- Number of years to recover the cost = Rs 300,000–60,000 = 5 years
- Payback period to recover the investment = 5 years

Source: G. Kavarana and S. Sengupta 2013, 'Catch water where it falls: Toolkit on urban rainwater harvesting', CSE.

Benefits of WSUDP:

The nature and extent of benefits will depend on local conditions (see *Figure 18: Benefits of WSUDP*). Local benefits include:

1. **Flood management:** Extensive use of WSUDP will lessen the amount of urban run-off into the drainage and sewer system and hence lessen run-off load. In addition, by reducing run-off load, WSUDP will contribute to the reduction of flooding risks.

2. **Controlling pollution content:** WSUDP provide a means of managing and treating urban pollution before returning it to waterbodies.

3. **Meeting water efficiency targets:** Some systems, such as RWH, provide an alternative source for non-potable water within domestic and commercial settings.

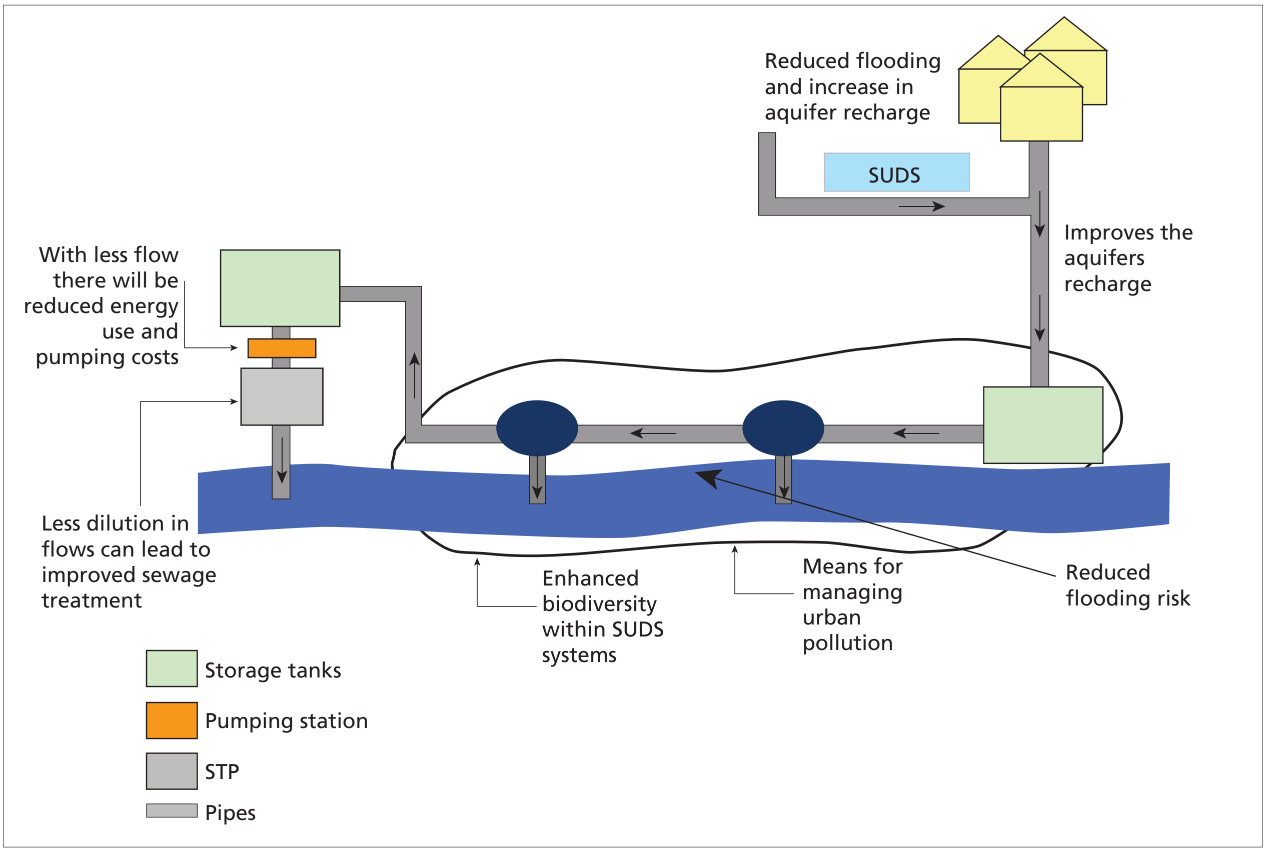
4. **Additional recharge of aquifers:** WSUDP provides a route for recharge thus helping to make savings on new water resource investment.

5. **Reducing energy costs:** Reducing or limiting volume of flow to the STP will help to reduce cost. Reduced pumping from storage facilities and less diluted sewage may result in more efficient treatment of wastewater.

6. **Enhancement of biodiversity:** WSUDP mimic the natural environment, retaining water that will attract wildlife, creating stable habitats and providing corridors along which wildlife can move.

7. **Effect of climate change:** Some SUDS approaches can help reduce the urban heat island effect. For example, adding 10 per cent green cover will keep maximum surface temperatures in high-density residential areas and town centres at or below the 1961–90 baseline up until the 2080s.

Figure 18: Benefits of WSUDP

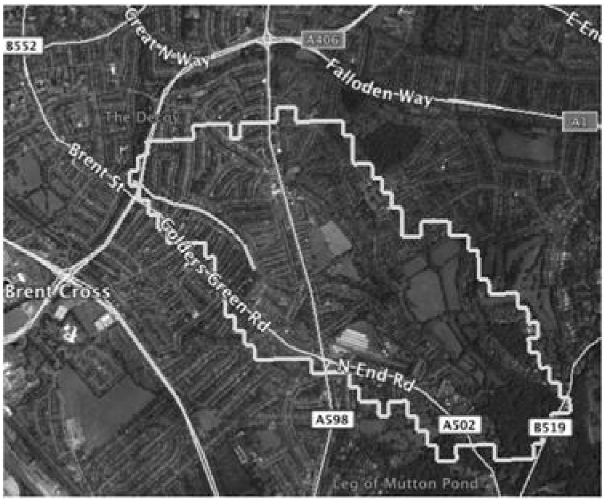


Source: Gordon-Walker, S., Harle, T. and Naismith, I., 2008. Cost-benefit of SUDs Retrofit in Urban Areas. Environment Agency.

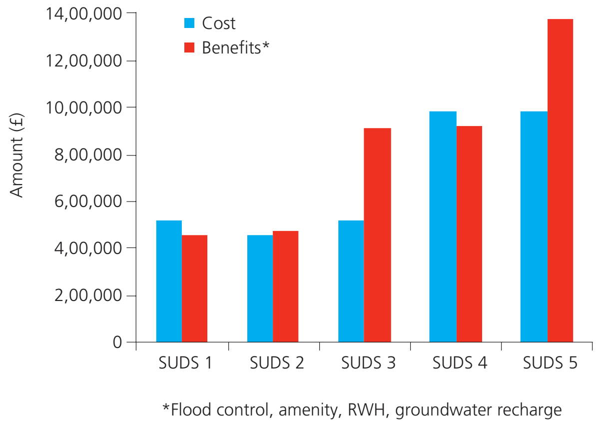
The following case study investigates the strategic role of SUDS retrofit in managing environmental risks to urban infrastructure at the catchment level through an economic appraisal of benefits (flood reduction and wider benefits).

CASE STUDY: Economic analysis of benefits to facilitate SUDS in London, UK

Year of economic research: 2017; Year of implementation: 2007



Catchment delineation from Google Earth



Relevance of individual benefits relative to the total value

Description

The Decoy Brook, north of London in the borough of Barnet, was chosen as a case study to simulate the impact of SUDS on the flood extension within the critical drainage area. It was assumed that the volume of water stored in the SUDS would reduce an equivalent volume of water on the updated flood maps for surface water.

The steps in the economic assessment of flood risk are as follows:

1. Identify properties and infrastructure at risk for a determined event.
2. Use the information available in the MCM to define the expected losses due to flooding of properties and infrastructure at risk.
3. Using at least three events with different return periods.
4. Define the effects of the selected SUDS scheme on flood maps (reduction of water levels) and repeat Steps 1 to 3 in order to define the average annual damage (AAD) with the scheme.
5. Find the difference between AADs determined in Steps 3 and 4 in order to define the average annual benefits of the intervention.

Source: Ossa-Moreno, J., Smith, K.M. and Mijic, A., 2017. Economic analysis of wider benefits to facilitate SUDS uptake in London, UK. Sustainable Cities and Society, 28, pp. 411–19.

Features

The total cost of each SUDS scheme, the value of the flood benefits, total value of all benefits (i.e. wider benefits + flood benefits), net present value and cost–benefit ratio for both classes of benefits is quantified.

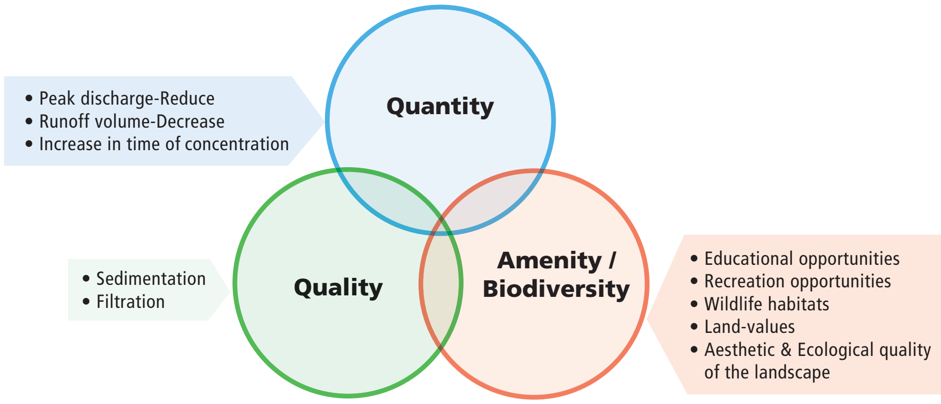
Results/observations

The analysis shows that WSUDP measures have positive economic returns when all benefits are examined. This confirms that basins are some of the most cost-effective SUDS available. It also shows that infiltration structures are the most cost-efficient ways of promoting SUDS and reducing flood risks to properties and infrastructure in hot spots.

4.4 Social and ecological impact of WSUDP approach

Growing urbanization has disturbed the natural hydrological cycle. The WSUDP approach is an attempt to restore and close the hydrological loop. The implementation of WSUDP intervention helps increase infiltration and groundwater recharge and improves runoff quality (see *Figure 19: Integrated impact of WSUDP*).

Figure 19: Integrated impact of WSUDP



Source: CSE, 2016

Similarly, the decentralized approach of treatment of wastewater and its reuse not only avoids drawing on natural resources but also enables a significant reduction in the amount of wastewater discharged into the natural environment. In fact, given the population explosion and ever-increasing water requirements, these natural technologies aiming at reuse offer genuine solutions. Once wastewater has been treated, it can also be used for various purposes, including agricultural irrigation, horticulture, car washing, flushing, maintaining streets and watering of green spaces etc.

Unlike conventional drainage, SUDS are likely to form part of public open spaces. They help promote interaction between communities and managing surface water that addresses pollutant reduction and flood control while providing habitat and amenity benefits.[7]

The WSUDP approach is an effective solution that plays a major role in returning clean, safe water to its source, leading to social and eventually ecological impact:

Social impact

The WSUDP approach has the following social impacts:

- It increases the aesthetic value of the area
- It creates a positive impact on passive and active recreation around the WSUDP asset (e.g. walking, jogging, cycling, bird-watching, etc.)
- It has a positive impact on individual and community well-being and welfare (e.g. social cohesion and economic prosperity)
- It reduces inconvenience associated with nuisance flooding (e.g. through temporary ponding in swales outside residential premises)
- It creates transport opportunities along and/or through the water/drainage corridor (e.g. walkways, cycle paths and bridges)

- Participation by local stakeholders leads to likelihood of associated behavioural change
- Increases availability of shallow groundwater for local reuse
- Benefits micro climate by shading/cooling, improving air quality and carbon sequestration from the use of vegetated storm-water treatment measures (e.g. wetlands, street trees that filter road runoff)

Ecological impact

- The impact on the value of having healthy aquatic and riparian ecosystems for potential use in the future (i.e. the impact on the 'option value' of these ecosystems)[9]
- Improves the landscape with blue-green amenities thereby improving the biodiversity of the area

5. Best management practices and case studies

With the increasing need for sustainable urban water management, cities across the world are demonstrating the implementation of innovative and affordable practices focusing on a holistic and integrated approach to water management. A review of select case studies was undertaken on a global scale to analyse the applicability and feasibility of such best management practices on different scales and agro-climatic conditions.

The following case studies consider aspects of the urban water cycle. Specific details of the case examples are also provided (see *Appendix E*). The select case studies show how coordinated spatial planning can be integrated with the following water-efficient practices:

- Managing surface water and flood risk
- Providing natural water treatment and pollution control
- Enhancing local water resources
- Improving biodiversity
- Providing public amenity/recreation space

Recycled and reused treated wastewater is often integrated with local water supply and water conservation as, for example, sewer mining projects in Australia. SUDS is another component of WSUDP that is increasingly being implemented globally. In numerous case studies, storm water is either incorporated into aquifer recharge schemes, or is used through harvesting to directly augment water supplies.[1]

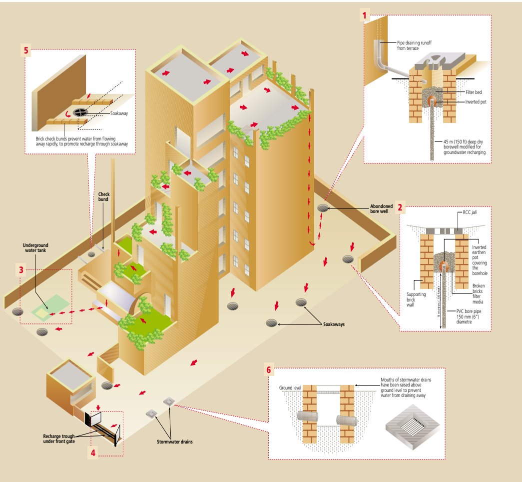
It has been found, however, that at present there are not many cities that have implemented all the components of WSUDP, i.e. water supply, wastewater reuse and storm-water management. Currently, Australia and Singapore are the main advocates of WSUDP and have implemented several projects that aim to integrate the management of the whole water cycle.

WSUDP intervention provides environmental, social and economic benefits. A significant benefit of this is the resilience that is developed for these cities. Environmental benefits such as reducing artificially increased volumes of storm-water runoff as a result of urban development and protection of groundwater resources can be achieved with storm-water management and aquifer recharge schemes. Social benefits are also seen as, for example, in the US where storm-water management using SUDS has been shown to improve urban aesthetics. Conversely, in some case studies it was found that social issues also have the potential to limit the adoption of WSUDP. This was mainly attributed to need for mindset change and lack of knowledge of the potential attempting to implement wastewater reclamation schemes, even though the current technology has proved that wastewater can be purified to safe, high-quality drinking water. As a result it is important to have the support of local communities when implementing WSUDP initiatives. It is evident from the various case studies and supporting literature that the main challenges of implementing WSUDP are not as much technological as social and institutional.[2]

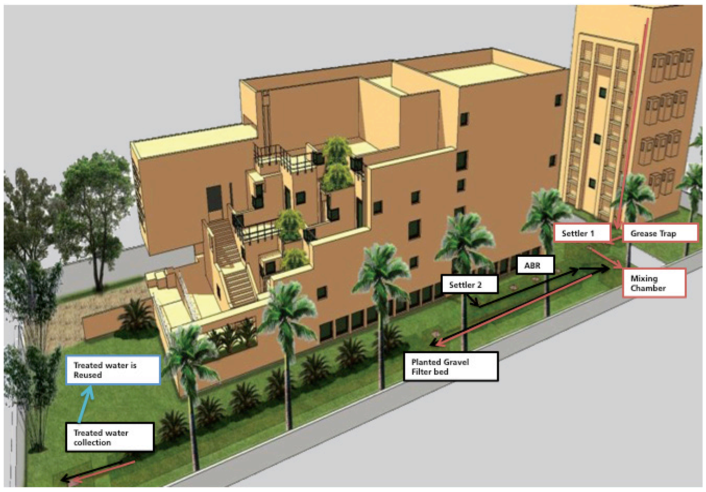
The following section illustrates the WSUDP approach of integrating water management at the strategic scale of planning and designing to achieve environmental, economic and social balance.

CASE STUDY: Local reuse of treated wastewater and rainwater harvesting at Centre for Science and Environment, New Delhi, India

Year of implementation: 1999 for RWH system and 2005 for DWWT system



Rainwater harvesting at Centre for Science and Environment



Decentralized wastewater treatment system at Centre for Science and Environment

Description

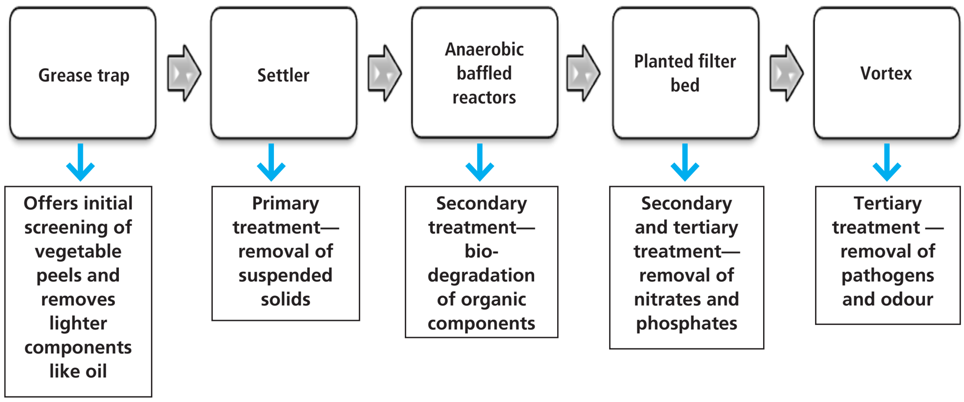
The CSE office in New Delhi has taken initiatives to be a water-sensitive institutional campus. Interventions include RWH and DWWT for local reuse.

Rainwater harvesting—The institutional-scale RWH system in CSE was implemented in 1999. It caters to a total area of 1,000 sq. m. The campus is located in south Delhi (Mehrauli block) where a groundwater decline of more than 20 m has been observed. The ridge area in Mehrauli block comprises hard rock at the surface and at shallow depths. The depth of groundwater is 50–100 mbgl. There are different RWH structures that ensure rainwater falling within the campus is captured, harvested and diverted into the aquifer. The system is designed according to average annual rainfall in Delhi, i.e. 611 mm in 1999.

Recharge trench	Recharge well	Recharge pits	Defunct borewell
To arrest water from flowing away	To recharge water from roof areas	To convey water to permeable soil layer	To recharge water from roof areas

Local reuse of treated wastewater—DWWT system was implemented in 2005 to treat both black water (wastewater from toilets) and grey water (wastewater from kitchen) on-site. The system is designed to treat about 8 KLD of wastewater with various components that combine to make the treatment successful and treated water reusable. The treated wastewater meets the desired water quality norms set by Pollution Control Boards and is reused for horticultural purposes (watering the lawn) on the CSE campus. Approximately 1,200 litres of treated wastewater is used for watering the lawn once.

Because of the various measures taken at the institutional campus for RWH and DWWT the following benefits are observed:



Features

CSE campus showcases a good example of water-sensitive designing at site level since it takes into account wastewater recycle and reuse as well as recharge of groundwater through rainwater. RWH and DWWT system have been incorporated within permissible open spaces as per building bylaws.

Results/observations

Adoption of WSUDP measures (RWH and DWWT for local reuse) has resulted in stagnation of depleting groundwater levels and creation of alternative water resource through local reuse of treated water.

- At least 366,600 litres (60 per cent of total rainfall) can be harvested annually. This harvested water amounts to approximately 1000 litres/day.

- For around 150 days* a year, treated wastewater is used to maintain greenery and landscaping the campus (150 x 1,200 = 180,000 litres/year). This is equivalent to ~35 water tankers of 5,000 litre capacity. Hence, a potential saving of Rs 35,000 (assuming market rate of water supply tanker is Rs 1,000).

  *(every alternate day except during the monsoon)

Source: G. Kavarana and S. Sengupta 2013, 'Catch water where it falls: Toolkit on urban rainwater harvesting', CSE; Rohilla, S. and D. Dwivedi. 2013., Reinvent, Recycle, Reuse – Toolkit on Decentralised wastewater Management, CSE.

CASE STUDY: Local reuse of treated wastewater at Aravind Eye Hospital, Puducherry, India

Year of implementation: 2003

Planted filter bed and polishing pond, part of the decentralized wastewater treatment system at Aravind Eye Hospital

Features

- The DWWTs is based on a natural process. It uses no chemicals for treatment.
- The DWWTs consists of a grease trap, settler, anaerobic baffled reactors (ABR), planted filter bed (PGF) and polishing pond for treatment. The system has been incorporated as part of landscape design at the site.

Observations

The hospital uses about 250,000 litres of water every day of which about 200,000 litres is treated and reused to water the gardens.

Description

The Aravind Eye Hospital in Thavalakuppam near Puducherry is a renowned hospital. It treats its wastewater through a DWWTs and reuses the treated wastewater.

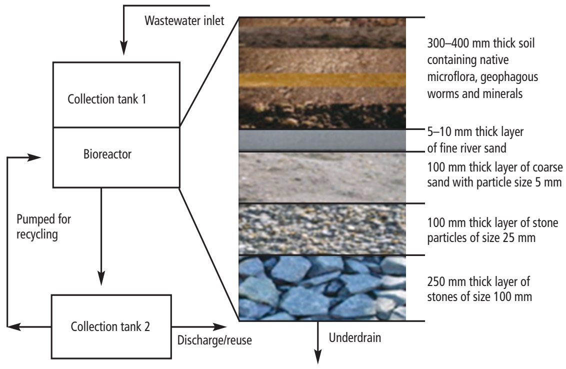
The institutional-scale DWWTs at the hospital, operational since 2003, is designed to treat 320 KLD of wastewater on a daily basis. Both grey and black water is treated by the DWWTs technology and the treated water is reused for maintenance of the 15 acres (6.07 hectares) of sprawling garden. Use of treated wastewater of about 200,000 litres (except during monsoon) is used for green landscape in the hospital campus with an estimated saving of about Rs 240,000 annually.

Source: youtubevedioweblink - https://www.youtube.com/watch?v=Pm5y_6iV1q0 (Source: BORDA & CDD), as access on 3 May, 2017

CASE STUDY: Local reuse of treated wastewater at Mumbai, Maharashtra, India

Year of implementation: 2002

Trickling of wastewater through pipes on the SBT reactor bed for its treatment



Schematics of SBT and the bio-reactor showing different layers of filter materials

Features

- Natural wastewater treatment with a capacity to treat 50KLD (50,000 litres per day)
- Minimal energy consumption (40-50 KWh per MLD) to pump the wastewater for distribution over reactor bed
- Capital cost (2002)—Rs 0.7 million
- O&M cost (annual)—Rs 0.1 million

Observations

The DWWT creates an alternative water resource used to maintain the green area inside the residential premises.

Description

The Naval Civilian Housing Colony is a residential neighbourhood for officers and their families in Kanjurmarg, Mumbai. It has 20 blocks of buildings with residential facilities, mess, hospital, sports complex, market area and administrative offices. The DWWT system implemented treats the wastewater generated in the neighbourhood from seven residential building blocks; each building has 24 apartments. The DWWTs at the site is based on soil biotechnology (SBT). SBT is a green technology for water purification using natural, novel high-efficiency oxidation process at competitive costs.

Raw water collection tank: Raw sewage after screening is collected in the tank from where it is directed towards the trench filled with gravels

↓

Constructed soil filter bio-reactor: Sewage is then pumped and distributed over the reactor bed

↓

Effluent collection tank: The treated sewage gets collected in this tank and is (re)circulated in order to achieve the desired quality of treated wastewater

Source: Rohilla, S.K. et al. (2014) Decentralised Wastewater Treatment and Reuse: Case Studies of Implementation on Different Scale – Community, Institutional and Individual Building. Centre for Science and Environment, New Delhi

CASE STUDY: Rainwater harvesting at community scale, Jodhpur, India

Year of implementation: 2010

Series of storage tanks similar to bawari

Vaulted walls for tank construction

Features

- Total catchment area—110 acres (44.51 hectares)
- Green area irrigated using harvested rainwater—15 acres (6.07 hectares)
- Capacity of RWH structure (bawari storage tank)—17.5 million litres
- Volume of rainwater harvested—approx 21.1 million litres per annum
- Cost of the system—Rs 80 million

Observations

The RWH system captures around 21.1 million litres of rainwater reducing the dependence on municipal water supply or groundwater extraction. The average cost of water tanker (10,000 litres per tanker) in Jodhpur is Rs 800–10,000. Thus by using the rainwater as alternative source of water about Rs 2.36 million is saved annually.

Description

The water table in Umaid Bhawan, Jodhpur, is low, 20–40 metres below ground level (mbgl). Birkha Bawari is a monumental RWH structure in Umaid Heritage, based on kunds and baoli that are traditionally used for RWH in Rajasthan and Gujarat.

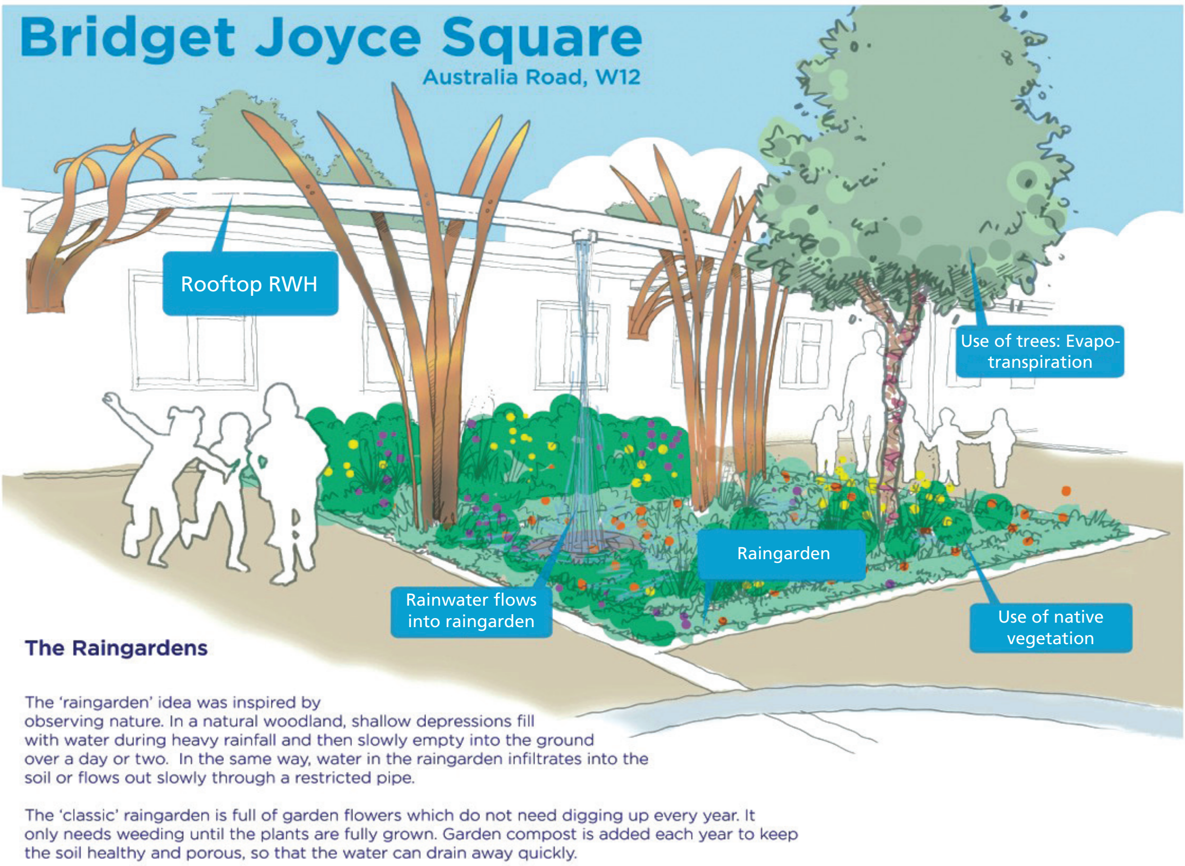
An RWH system to collect rainwater falling on the entire site has been developed. Rain is collected in an open storage designed similar to a bawari and integrated with the housing complex as a recreational area. The RWH system collects around 30 per cent of the rainwater on the site which is used for horticultural purposes.

The rainwater is collected from rooftops and road channels through storm-water drains, open channels and slots. The runoff from apartments is collected from the storm drains and connected to the drains sloping towards the Birkha Bawari.

The Birkha Bawari comprises longitudinal open rainwater storage structures in series, making it a linear 135-metre-long structure. Water enters from both sides of the underground longitudinal storage structures (bawari), which hold 17.5 million litres of harvested rainwater annually that serves as a rich source of water for landscaping water requirements of green area in an otherwise water-scarce region. The bawari structure acts as a recreational space for inhabitants as well as storage structure of rainwater.

Source: Rohilla, S.K. et al. (2014): URWH, case studies from different agro climatic regions. CSE.

CASE STUDY: Bridget Joyce Square (Australia Road), White City, London
Year of implementation: 2013



Features

- SUDS components used—permeable paving, planted basins, rain gardens, tree planting and downpipe
- Total site area—2,700m^2
- Length of carriageway—121m
- Permeable paving—1,320m^2
- Planted basins—335m^2
- Raingardens—120m^2
- Number of trees—49

Results/observations

- Reduction in local and wider flood risk.
- Annual flow volumes into the combined sewer overflow have been reduced by 50 per cent.

Description

The project is located between a school and two playgrounds in the heart of White City district. The pervious road and parking formed a flood hazard for children crossing the road and made school drop-off and pick-up difficult.

The scheme creates an urban public park through the use of traffic restrictions, new surfacing, new elements of green infrastructure and street furniture that forms a valuable community resource whilst helping to reduce the area's contribution to flooding. The objective is to create a space where landscape serves a vital drainage function providing flood resilience against known surface water and sewer flooding issues in the area and provides local climate change adaptation benefits.

The scheme also provides connectivity and a safer pedestrian passageway between Wormholt Park and Hammersmith Park. Post-implementation carriageways adaptations have made the area and its community assets safer.

Source: CIRIA weblink: http://www.susdrain.org/case-studies/case_studies/bridget_joyce_square_london.html

6. The way forward

This practitioner's guide shows how to manage water in a sustainable way by looking into gaps in existing policies, plans and guidelines of India and suggesting the most suitable ways forward.

WSUDP strategies have been observed to bring multiple benefits such as recreational opportunities, amenities and biodiversity. This guide is intended to provide an opportunity for ULB officials to integrate sustainable water management with multiple benefits.

With the WSUDP approach as a multi-disciplinary process, a city's transition from a water-wasteful to a water-sensitive environment within a range of social-economic and environmental context can be facilitated. This guide develops a critical mass of knowledge around the integration of planning and designing activities for the adoption of water sensitivity in urban areas of India (*see Posters: WSUDP approach at different scales* and *WSUDP in different densities*).

Appendix

A. Review of regulatory framework dealing with urban water management in India

Policy	Existing key focus	Status of potential WSUDP intervention
National Water Policy, 2012	Drinking water supply and management	No mention about sustainable water management or water sensitive practices at different scales
National Land Utilisation Policy, 2013	Improvement of livelihood, food and water security, and best possible realization to ensure sustainable development of India	No focus on the use of conserved land for SUDS structures and implementation of WSUDP projects
National Housing Policy of India, 2015	'Affordable Housing for All' with special emphasis on the urban poor	No mention of integration of various environmental factors towards sustainable water management
Plan	**Existing key focus**	**Status of potential WSUDP intervention**
12th Five Year Plan	Restoring traditional water bodies and natural drainage systems. Encourage Integrated Watershed Management Programme	Provision and platform to implement WSUDP structures
Master Plan, 2021	Guides the process of planned development of an urban area	Vision statement and the demand assessment don't keep pace with each other Doesn't talk about the use of open spaces for implementation of WSUDP projects
Guidelines	**Existing key focus**	**Status of potential WSUDP intervention**
Urban and Regional Development Plans Formulation & Implementation (URDPFI) Guidelines, 2014	Prepares the proposed land use bifurcation for different urban centres	Provides enough open area to design the SUDS structures
Guidelines and Benchmarks for Green Large Area Development, 2011	Developing a 'green campus/ townships'	Need to be upgraded to the next level i.e. city level and add its input in the existing master plans Perception of three level of scales needs to be included
Environmental building guidelines for Hyderabad Metropolitan Development Authority, 2009	Assess of the present and future environmental issues in the building industry	Needs to be scaled to city level and also cover rest of the aspects/components of WSUDP
Environment Impact Assessment	Obtaining clearance for scheduled development projects that are likely to result in significant environmental effects	Crucial environment factors are not conspired e.g. consumption of water, increase runoff
Bureau of Indian Standards (BIS)—Drinking Water Quality	Specifies the acceptable limits and permissible limits in the absence of alternative source	Storm water and wastewater outputs should not affect the drinking water standards

Storm water Index—National Mission on Sustainable Habitat, 2015	Assess and monitor the implementation of sustainable storm-water management Helps to quantify the sustainability of drainage system as well as urban drainage	Rainwater Harvesting/Artificial Groundwater Recharge Index Benchmark: (1.0) the ratio of the measured value of Total Suspended Solids (TSS)/Bio-chemical Oxygen Demand (BOD) of the storm drain water to the prescribed limits of TSS/BOD Rainfall Intensity Index Benchmark: (Variable) the ratio of the observed rainfall intensity to the rainfall intensity which causes flooding in that particular area. Storm-water discharge quality Index Benchmark: (0.3) the ratio of the rainwater volume stored/harvested to the ratio of the measured rainfall volume.
Model Building Bye-Laws, 2016	Provisions for rainwater harvesting, green buildings, segregated toilets, wastewater reuse and recycle etc.	Emphasis is given on consumption of up to 30 per cent potable water and generate approximately 40 per cent of total waste with provisions for water conservation and management by rainwater harvesting, low water consumption plumbing fixtures, wastewater recycle and reuse, and reduction of hardscape

Source: CSE, 2016

In urban areas, developmental works are carried out on construction of different types of buildings and infrastructure works such as road, water supply, sewage and rainwater (storm-water) drainage networks. These developmental works can be associated with high or low environmental impact depending on how significant the impact is. Submission of the EIA report is a statutory requirement for obtaining prior environmental clearance under the EIA Notification 2006 for scheduled development projects that are likely to result in significant environmental effects. Water-related considerations such as water supply and demand management, storm-water management and wastewater management are vital in an EIA report. Crucial environmental aspects such as consumption of water for the project, sewage generation from the project, sewage treatment plant for the township and increase in run-off from the site due to buildings, roads, paver blocks and other hard surfaces need to be taken as serious considerations. *Table: Environmental aspect and their associated impact developments* highlights the already existing provisions supporting WSUDP that can have an positive impact on the environmental.

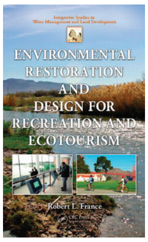
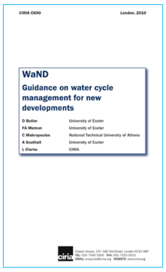
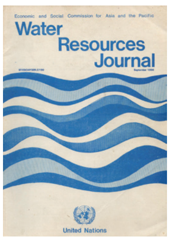
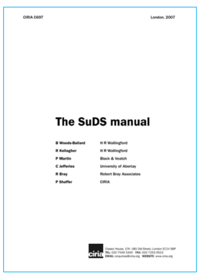
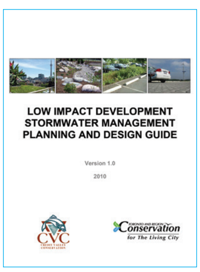
Table: Environmental aspect and their associated impact developments

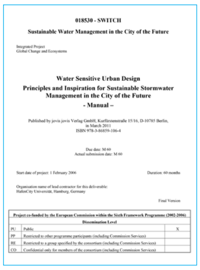
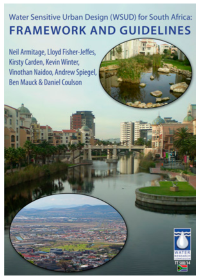
High-impact development	Low-impact development
Environmental aspect: Water supply and demand	
Tapping from the already overloaded header pipe line of the service provider and have significant impact to the competing users or Abstraction of groundwater and will lead to depletion of groundwater reserve.	Provision of large rainwater storage ponds to store the roof run-off or surface run-off and use it with minimal treatment (filtration and disinfection)

Use of water intensive sanitary fixtures and thereby no control of water consumption and have significant impact to the competing users.	Use of water efficient sanitary fixtures: a. Low flow, high pressure water taps, showers etc. b. Double button cistern for flushing
No recycling of treated sewage and all water requirements are met by fresh water and have significant impact to the competing users.	Recycling of treated sewage by installation of dual plumbing and using the treated sewage to meet the non-potable requirements.
Environmental aspect: Wastewater	
Discharge to the already overloaded sewerage system of the service provider or Discharge to surface water, open land and these activities will lead to the contamination of surface water and groundwater.	Treatment of sewage through STP and recycling the treated water from STP.
Centralized STP with cross-country sewer lines will have less efficiency, more transfer cost, more leakages and will have significant impact. or More ingress and inflow during rainy days from the laid underground sewer lines and will increase the sewage load many folds.	Decentralized treatment plants adjoining the source of generation with less sewer lines.
Environmental aspect: Storm water	
No RWH structure or percolation pits. or Three time increase in the runoff from the site overloads the laid storm-water pipes/drains of the service provider and lead to flooding or stagnation of large quantity of runoff near the site if there is no storm-water drain and all these leads to flooding.	RWH percolation pits and thereby to achieve zero discharge of storm water from the site.
Environmental aspect: Groundwater	
Deterioration in groundwater quality and decrease in groundwater table	Infiltration and recharge helps to maintain water table

Source: Thomas, P. Z., (2013) Presentation on Water Neutral in Low Impact Urban Developments in Regional Workshop on 'Energy and Resource Efficiency in Urban Water Management' in Puducherry on 12 August 2013

B: Recommended reading material

<table>
<tr><td>
</td><td>Morgan, C., Bevington, C., Levin, D., Robinson, P., Davis, P., Abbott, J. and Simkins, P., 2013. Water sensitive urban design in the UK. Ideas for built environment practitioners. CIRIA report C, 723.</td></tr>
<tr><td>
</td><td>France, R.L. ed., 2002. Handbook of water sensitive planning and design. CRC Press.</td></tr>
<tr><td>
</td><td>Butler, D., Memon, A., Makropoulos, C., Southall, A. and Clarke, L., Guidance on Water Cycle Management for New Developments. CIRIA Report C, 690.</td></tr>
<tr><td>
</td><td>Wong, T.H., 2006. Water sensitive urban design-the journey thus far. Australian Journal of Water Resources, 10(3), pp.213-222.</td></tr>
<tr><td>
</td><td>Ballard, B.W., Kellagher, R., Martin, P., Jefferies, C., Bray, R. and Shaffer, P., 2007. The SUDS manual. Construction Industry Research & Information Association (CIRIA).</td></tr>
<tr><td>
</td><td>Dhalla, S. and Zimmer, C., 2010. Low Impact Development Stormwater Management Planning and Design Guide. Stormwater Guide. Toronto: Toronto and Region Conservation Authority</td></tr>
</table>

 018530 - SWITCH Sustainable Water Management in the City of the Future Integrated Project Global Change and Ecosystems Water Sensitive Urban Design Principles and Inspiration for Sustainable Stormwater Management in the City of the Future - Manual – Published by jovis jovis Verlag GmbH, Kurfürstenstraße 15/16, D-10785 Berlin, in March 2011 ISBN 978-3-86859-106-4 Due date: M 60 Actual submission date: M 60 Start date of project: 1 February 2006 Duration: 60 months Organisation name of lead contractor for this deliverable: HafenCity Universität, Hamburg, Germany Final Version Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006) Dissemination Level PU Public X PP Restricted to other programme participants (including Commission Services) RE Restricted to a group specified by the consortium (including Commission Services) CO Confidential only for members of the consortium (including Commission Services)	Hoyer, J., Dickhaut, W., Kronawitter, L. and Weber, B., 2011. *Water sensitive urban design: principles and inspiration for sustainable stormwater management in the city of the future*. Hamburg, Germany: Jovis.
 	Armitage, N., Fisher-Jeffes, L., Carden, K., Winter, K., Naidoo, V., Spiegel, A., Mauck, B. and Coulson, D., 2014.*Framework and Guidelines (WRC).*

C.1: Checklist for sustainable urban drainage systems

BASIC INFORMATION

NAME OF THE BUILDING/PROJECT:______________________________

NAME OF THE IMPLEMENTING AGENCY:______________________________

LAND USE:

Residential	
Institutional	
Transport	
Commercial	
Other	

ADDRESS:______________________________

CITY:____________________STATE:____________________

PHONE:____________________EMAIL:____________________

DATE OF SURVEY: ____________________

I. TECHNICAL DATA

Catchment area

Type of catchment	**Dimensions (length x width)**	**Area**	**Remarks**
Paved			
Road			
Footpath			
Concreted			
Other			
Unpaved			
Green-vegetated			
Grass			
Soil			
Other			
Rooftop			
Other			

*Photographs of each catchment surface

Conveyance of storm water

Longitudinal slope	Inlet	Outlet/overflow	Any other feature for handling the flow

*Photographs of each conveyance mechanism

Type of SUDS structure

Structure is similar to? (Photograph)

Swale	
Bio-retention area/rain garden	
Detention basin	
Pond	
Other	

Cross section conceptual drawing (with side slope)

Attributes	Value
Surface area and dimensions	
Depth	
Total capacity	
Other feature/remarks	

Surrounding buffer area

Attributes	Value
Surface area and dimensions	
Land cover	
Other feature/remarks	

C.2: Checklist for decentralized wastewater treatment for local reuse

The following questions will provide basic information for a feasibility assessment of DWWTs:

1. BACKGROUND

I. Land use:

II. Municipal sewage connection: Available/Not available

If available, information on sewage drains in campus

- Underground drainage (covered within campus):
- Open drainage (covered within campus):

III. Septic tank or other on-site sanitation system (e.g. soak pit): _________/capacity___________(litres)

IV. Describe any pre-treatment facilities or practices used to remove chemical/hazardous pollutants to protect the sewer if any: ____

V. Storm water discharge from campus: In the drainage/overland flow

VI. Open area available in campus: Yes/No (Appox. area: ___________sq. m)

VII. Green area in campus: _________ (sq. m)

VIII. Any forest clearance issue for trees in campus: Yes/No

2. WATER SUPPLY AND CONSUMPTION

I. Source of water supply : Municipal bore well/municipal supply/tanker

II. Number of storage tanks in campus: Yes/No

Tank1:____________ (litres), Tank 2 :__________ (litres), Tank 3 :__________(litres)

III. Estimated daily water consumption: _____________ (litres)

- Number of users: Permanent ______________; Visitors _________________.
- Capacity of the overhead tank; number of times the overheard tank is emptied per day: ____________________
- Water usage in garden/ landscaping: ___________________

3. GEO-HYDROLOGICAL INFORMATION:

I. Water table depth: ___________ (metres below ground level)

II. Bore well log available: Yes/No—Location of bore well on the site plan

III. What is the nature of soil in the area?

Sandy/clayey/silty-clay/other

4. WASTEWATER GENERATION SOURCES:

I. Number of users:

- Buildings: Yes/No

  (No. of buildings in institution:___________; Building type : Single/multistory; Number of floors__________ (write separately for each building)

- Kitchen/canteen: Yes/No

  If yes, number of users/day:___________

I. No. of toilets in the building/s: ___________; location on site plan: _________

II. Any use of phenyl, detergents or other chemical substances mixed with wastewater for cleaning

III. Are there separate pipelines for grey water (which comes from kitchens, washbasins and bathrooms) and black water (which comes from toilets)? Yes No

5. Please attach the following:

a. Architectural drawings (site plan with dimensions) indicating:

- Location of wastewater generation sources
- Open area and built up area
- Sewer drains with flow directions
- Services layout (water supply, fire fighting storage, electric cables etc.)
- Slope direction
- Location of the storage tanks
- Rooftop/terrace floor plan showing the location of rainwater pipes/outlets
- Location of abandoned/defunct bore or tube wells (if any)

b. Any data on wastewater quality analysis (BOD, COD, total phosphate, TKN, total coliform etc.).

c. Any relevant information you would like to provide

D.1: Operation and maintenance of sustainable drainage systems

Operation and maintenance activity	SuDS component												
	Pond	Wetland	Detention basin	Infiltration basin	Soakaway	Infiltration trench	Filter drain	Modular storage	Pervious pavement	Swale/bioretention/ trees	Filter strip	Green roofs	Proprietary treatment systems
Regular maintenance													
Inspection	■	■	■	■	■	■	■	■	■	■	■	■	■
Litter and debris removal	■	■	■	■	□	■	■	□	■	■	■		□
Grass cutting	■	■	■	■	□	■	■	□	□	■	■		
Weed and invasive plant control	□	□	□	□		□	□		□		□	■	
Shrub management (including pruning)	□	□	□	□					□	□	□		
Shoreline vegetation management	■	■	□										
Aquatic vegetation management	■	■	□										
Occasional maintenance													
Sediment management[1]	■	■	■	■	■	■	■	■	■	■	■		■
Vegetation replacement	□	□	□	□						□	□	■	
Vacuum sweeping and brushing									■				
Remedial maintenance													
Structure rehabilitation /repair	□	□	□	□	□	□	□	□	□	□	□	□	
Infiltration surface reconditioning				□	□	□	□		□	□	□		

Key

■ will be required

□ may be required

Notes

1 Sediment should be collected and managed in pre-treatment systems, upstream of the main device.

D.2: Operation and maintenance activities for decentralized wastewater treatment for local reuse

Components	Method of maintenance	Time frame for monitoring and maintenance (short term—S, long term—L, when required—R)
Grease trap	• Skim upper scum layer (oil layer) • Hydrant-flushing, in case of clogging • Cleaning of the unit to achieve required free flow of wastewater and avoid clogging	S R R
Settler	• Non-degradable substances such as plastic, glass, metals etc should be checked • Desludging the unit once in 2-3 years • While emptying/desludging some active sludge should be left to enable continuous decomposition of fresh influent	S L L
Anaerobic baffled reactor	• Surrounding of the units should be kept free of plants in order to prevent roots from growing and crack/ crevices in the structure. • Filters materials should be removed, washed cleaned and then put it back in five to ten years • Desludging the unit once in two to three years • While emptying/desludging some active sludge should be left in system to enable continuous decomposition of fresh influent • Dead leaf litter should be removed	S L/R L L R
Planted filter bed	• Harvesting of plants • Prevent runoff from surrounding • Optimal water distribution	R L R
Oxidation pond	• Prevent algal boom • To prevent stagnancy, wastewater should be reused for horticulture after 24–48-hour detention	S

*Short term: less than one year; long term: once in two to five years

E. List of worldwide case studies reviewed

S. no.	Country	Site and city	Scale	Outcomes	Sources and references
1	USA	Tanner Springs Park, Portland	Public park	Re-establishment of natural wetland, creation of a functional, beautiful public park in a dense urban area	www.plannersweb.eu, www.drainforlife.eu, Case Studies Sustainable Water Management in the City of the Future (pdf)
2		10th @ Hoyt Apartments, Portland	Courtyard	Reduces the excess runoff rate, suspend solids and pollutants by using rainwater harvesting system	Case Studies Sustainable Water Management in the City of the Future (pdf) Water Sensitive Urban Design for a Sustainable Stormwater Management in the city of the Future - SWITCH Research Results (pdf)
3		Fig Tree Place, Hamilton	Residential	Demands on water supply reduced by 60% through stormwater management	www.researchgate.net Water Management to water sensitive urban planning—A contemporary approach to sustainable planning (pdf), Water Sensitive Urban Redevelopment: The 'Figtree Place' Experiment (pdf)
4		Portland, Oregon,	City	Grey to green initiative—Use of green roofs, infiltration areas, pervious surface materials, and other such measures demonstrates that decentralized approach can function on their own and be linked together to manage storm water on district or even potentially at an urban scale	Water Sensitive Urban Design Principles and Inspiration for Sustainable Stormwater Management in the City of the Future—Manual

5		Portland, Oregon,	Public park	Using sustainable storm-water management to re-establish natural wetlands and create a functional, beautiful public park in a dense urban area.	Water Sensitive Urban Design Principles and Inspiration for Sustainable Stormwater Management in the City of the Future—Manual
6	Germany	Trabrennbahn Farmsen, Hamburg	Residential	Aesthetic benefit, Groundwater Recharge through vegetated swales and retention basins	Case Studies Sustainable Water Management in the City of the Future (pdf), Water Sensitive Urban Design for a Sustainable Stormwater Management in the city of the Future—SWITCH Research Results (pdf)
7		Hohlgrabenäck-er, Stuttgart	Residential	Preservation of natural hydrological cycle through stormwater management and water conservation	Case Studies Sustainable Water Management in the City of the Future (pdf), Sustainable Urbanism with Green Roofs—Natural Stormwater Management (pdf)
8		Potsdamer Platz, Berlin	Residential	Maintains ecological balance, contributes to environmental conditioning, focal point for outdoor recreation	Case Studies Sustainable Water Management in the City of the Future (pdf), How can Urban Stormwater Design contribute to a successful site design - Jack Radar (pdf)
9		Trabrennbahn Farmsen (Hamburg)	Residential	Application of an open drainage system as a key design element for a newly built residential estate; design reflects the former function of the site as a harness racetrack.	018530 - SWITCH Sustainable Water Management in the City of the Future
10	South Korea	Juyeop Elementary School	Institution	Recycled water used for toilet flushing, irrigation, gardening and spaying for playground	Water Resource Management: Policy Recommendations for the Development of Eco-efficient infrastructure (pdf)
11		Star City, Seoul	Commercial	Flood mitigation, water conservation, 47% water captured	www.iwawaterwiki.org Water Resource Management: Policy Recommendations for the Development of Eco-efficient infrastructure (pdf)
12		Gangneung sports comple, Gangneung	Recreational	Treated water used in gardening, spraying, toilet, flushing, fire fighting	Water Resource Management: Policy Recommendations for the Development of Eco-efficient infrastructure (pdf)
13		Asan New City	City	Restoration of water cycle, Security of alternative water resources by rainwater use, education of water-related disasters, Promotion of Green new technologies	Water Resource Management: Policy Recommendations for the Development of Eco-Efficient Infrastructure (pdf), Choi, Hanna (2011) New city planning with decentralized rainwater management based on LID, Symposium on decentralized rainwater management
14		Juyeop Elementary School	Residential	Rainwater management system is installed and rainwater is used for toilet flushing, irrigation, gardening and spaying for playground.	Kim et al., (2012) Low Carbon Green Growth Roadmap for Asia and the Pacific
15	Netherlands	Het Funen, Amsterdam	Residential	Groundwater recharge through storm-water management	Comparative Case Studies towards mainstreaming Water Sensitive Urban Design in Australia and the Netherlands (pdf) Mainstreaming Innovations in Urban Water Management (pdf)
16		Duyfrak, Valkenburg Zh	Residential	Rise in the water table through storm-water infiltration and permeable pavement	Comparative Case Studies towards mainstreaming Water Sensitive Urban Design in Australia and the Netherlands (pdf) Mainstreaming Innovations in Urban Water Management (pdf)
17		Rotterdam,	City	Using water as an opportunity to make a city more attractive by creating and implementing new solutions for storm-water storage in densely built urban areas and by following an integrative approach	Water Sensitive Urban Design Principles and Inspiration for Sustainable Stormwater Management in the City of the Future—Manual

18	India	IIM Kozhikode, Kerala	Institution	Self-sufficient (no external water supply), Zero runoff	www.indiawaterportal.org, Water Management to water sensitive urban planning- a contemporary approach to sustainable planning (pdf)
19	Philippines	DOST 7 Office Building, Cedbu City	Commercial	75% of the water need is fulfilled - Reuse for toilet flushing and Gardening Recycled wastewater released to the river for ecosystem	Water Resource Management: Policy Recommendations for the Development of Eco-efficient Infrastructure (pdf), Reeho Kim, The integrated rainwater and greywater management project in Cebu, Philippines, Low impact development symposium, Pennsylvania. 2011
20	Malaysia	Kuching	City	Groundwater recharge and reduction in potable water use by treating grey water	Water Resource Management: Policy Recommendations for the Development of Eco-efficient Infrastructure (pdf), Greywater Management in Low and Middle-Income Countries, Sandec (Water and Sanitation in Developing Countries) at Eawag (Swiss Federal Institute of Aquatic Science and Technology), 2006
21	Mali	Djenne	City	Grey water treatment system	Water Resource Management: Policy Recommendations for the Development of Eco-efficient Infrastructure (pdf), Greywater Management in Low and Middle-Income Countries, Sandec (Water and Sanitation in Developing Countries) at Eawag (Swiss Federal Institute of Aquatic Science and Technology), 2006
22	Jordan	The Dead Sea Spa Hotel	Commercial	17% of the water consumed in the hotel is recycled	Sustainability in the Hospitality Industry: Principles of Sustainable Operations, www.afedonline.org/water%20efficiency%20 manual/PDF/7Appendix%20A_Case%20 Studies.pdfs,
23		The Aqaba Residence	Residential	300 cum of water is saved per year. Recycled water is used in irrigation and Landscaping	AREE - Aqaba Residence Energy Efficiency www.afedonline.org/water%20efficiency%20 manual/PDF/7Appendix%20A_Case%20 Studies.pdfs
24	England	Hastoe Housing Association development, Upcher Close, Norfolk	Residential	Reduction in per capita water consumption	Water Efficiency in New Developments: A best practice guide (pdf) Waterwise East: 2007-2010
25		Stamford Brook development	Residential	A good example of how holistic water management, can be incorporated into a development scheme to ameliorate flood risk and improve environmental quality and a series of connected greenways and wildlife corridors.	Delivering Sustainable Housing—Learning from Stamford Brook
26		Upton, Northampton	Community	A mid-density residential neighbourhood with integrated SUDS, providing significant additional housing without increasing flood risk while retaining effective greenfield runoff rates, and reducing flood risk to the wider community	Planning advice for integrate water management—Cambridge Natural Capital Leaders Platform
27	Australia	Evermore Heights, Rockingham	Zone	68% reduction in water use scheme by using WSDP structures	Evermore Heights NWW case study VI pdf UDIA Sustainable Urban Development Matrix (pdf) http://www.rowegroup.com.au/portfolio/evermore-heights-residential-estate

28		Carindale Pines, Brisbane, Queensland	Residential	All homes constructed on the site include a 25 kL rainwater tank, collecting rainwater after filtering through a first-flush system. Tank water is used for all household uses, including drinking water. Additionally, homes are fitted with AAA-rated water-saving appliances. On a larger scale, roads in the development were designed to conform with natural landforms where possible, and catchment runoff is directed through a series of vegetated swales.	Evaluating Options for Water Sensitive Urban Design—A National Guide Appendices
29		Mawson Lakes Boulevard	City	An integrated water management approach was adopted in Mawson Lakes with different WSUD elements (storm water, recycled water) and landscape features (lakes and open spaces). The local runoff from the development is diverted to the wetlands (railway wetlands) on the south west of the development by storm-water infrastructure further via a culvert to the Greenfields wetlands to the west (City of Salisbury n.d. b).	Water Sensitive Urban Design Impediments and Potential: Contributions to the SA Urban Water Blueprint Post-implementation assessment and impediments to WSUD
30		The Grove: Leading Learning, Living, Peppermint Grove	Commercial	Groundwater recharge- Reduction in the demand on the mains water supply by 730,000 L each year. Meeting 100% of the internal water demand. Water-efficient fixtures save 175,000 L each year. Reduction in groundwater withdrawal by 700,000 L per year	Case 2 186 The Grove: Leading, Learning, Living May 2012 (pdf) Case2 186 The Grove: Leading, Learning, Living: Final Report for the Green Precints Fund
31		CERES, Brunswick, Victoria	Local (community and educational facility)	With integrated approach of storm water, water conservation and wastewater treatment and reuse is able save water to 1 ML/yr	SEWaC, 2012. Ceres Zero Emissions by 2012. Green Precincts Final Report. Australia: SEWaC (Department of Sustainability, Environment, Water, Population, and Communities). http://www.environment.gov.au/water/policy-programs/green-precincts/ceres/index.html [accessed Nov 2012].
32		Capricorn, Perth	Zone	Storm-water management and water conservation through swales, raingardens, living streams and retention of native vegetation	Case 4 132 Capricorn Final Oct 2011 (pdf)
33		The Green at Brighton, Perth	Zone	50% reduction in household use water through stormwater management and water conservation	Case 5 123 The Green at Brighton Final sept 2011 (pdf) community responses towards a communal groundwater irrigation system in Perth (pdf) Demonstration Projects: Case studies from Perth, Australia (pdf)
34		Bellair Street, Kensington	Residential	Decrease in pollution by using raingardens	Case 8 Bellair Street Raingardens—Sample Case Study (pdf)
35		Lynbrook Estate, Melbourne	Residential	Significant pollution reductions, groundwater recharge through vegetated swales, bio-retention and integrated wetlands	Water Management to water sensitive urban planning—A contemporary approach to sustainable planning (pdf) A case study in WSUD: Lynbrook Estate, Melbourne, Australia (pdf)
36		Victoria Park, Sydney	Zone	SUDS approach for Groundwater recharge	Concept Design Guidelines for Water Sensitive Urban Design (pdf) Developing Sustainable Places—-Land.com (pdf)

37		Kogarah town square, Sydney	Zone	85% storm water captured, 42% reduction in potable water through water efficient fixtures and storm-water collection and reuse	http://www.architectsajc.com/projects/kogarah-town-square/ Water Management to water sensitive urban planning- a contemporary approach to sustainable planning (pdf)
38		Healthy home, Gold Coast, Queensland	Residential	Significant reduction in potable water use and the wastewater generated, rainwater collection and treatment	Water Management to water sensitive urban planning- a contemporary approach to sustainable planning (pdf)
39		60L Green Building, Carlton, Melbourne	Commercial	Involves integrated approach—storm-water management, water efficient fixtures and wastewater management	Water Management to water sensitive urban planning- a contemporary approach to sustainable planning (pdf)
40	South Africa	Anglican Cathedral, Central Business District, Pietermaritzburg	Parking lot	Runoff flows across an impermeable area onto permeable pavers. The runoff is filtered through the permeable paving structure. The filtered runoff is discharged into the municipal storm-water system	Report to the Water Research Commission By Neil Armitage, Michael Vice, Lloyd Fisher-Jeffes, Kevin Winter, Andrew Spiegel & Jessica Dunstan (2012)
41		eThekwini Municipal, Central Business District; Durban	Residential	Roof collects and effectively attenuates Storm water over its surface area	Report to the Water Research Commission By Neil Armitage, Michael Vice, Lloyd Fisher-Jeffes, Kevin Winter, Andrew Spiegel & Jessica Dunstan (2012)
42		Hawaan Forest Estate, Umhlanga Rocks, eThekwini	Residential	The development maintains upstream conditions using SUDS treatment trains prior to the discharge of storm water into the Hawaan Forest downstream	Report to the Water Research Commission By Neil Armitage, Michael Vice, Lloyd Fisher-Jeffes, Kevin Winter, Andrew Spiegel & Jessica Dunstan (2012)
43	China	Chinese 'Sponge Cities' Will Capture Rainwater	City	Existing grey infrastructure in China cannot cope with rapid urban expansion and frequent droughts and floods. Several cities, with Beijing's approval, are experimenting with rainwater capture methods as an alternative.	http://www.planetizen.com/node/79484/chinese-sponge-cities-will-capture-rainwater
44	Scotland	Dunfermline, Perth	Residential and commercial	Agricultural land was developed to SUDS case study site to resolve issues related to flooding and pollution in water courses	http://www.susdrain.org/case-studies/case_studies/dunfermline_eastern_expansion_scotland.html
45		Ardler Village, Dundee	Residential	Multi-storey building were demolished to reduce flooding at town centre and new storm-water management systems were installed by considering green space and amenity factors	https://repository.abertay.ac.uk/jspui/bitstream/handle/10373/1992/Wade_SmartSUDS_Author_2015.pdf?sequence=2

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Centre for Science and Environment
41, Tughlakabad Institutional Area,
New Delhi 110 062 Phones: 91-11-40616000
Fax: 91-11-29955879 E-mail: cse@cseindia.org
Website: www.cseindia.org