Water Sensitive Urban Design (WSUD) for South Africa:
FRAMEWORK AND GUIDELINES

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Executive summary

PART 1: WSUD framework for South Africa

Introduction and background

South Africa (RSA) is a water-scarce country challenged with transforming its unsustainably resource-intensive economy whilst also addressing the legacy of Apartheid (DWA, 2013). The adequate provision of water to RSA's citizens is one of the most significant challenges facing the country. If a water crisis is to be averted, existing systems will need to be managed effectively (Muller *et al.*, 2009), both in terms of quantity of resources as well as quality. This is particularly relevant in the rapidly-urbanising areas owing to the fact that they are hubs of economic growth, and could without proper management become major drivers for increased water demand. It is evident that alternative, systems-based approaches to conventional water management of water supply and modes of ensuring water quality are required. A systems approach with multiple objectives is called for; one that takes into account community values and aspirations when dealing with water supply, wet and dry sanitation, biological and chemical treatment of associated contaminants, drainage and the management of industrial effluents, whilst also acknowledging the range of users, including: residential, institutional, commercial and industrial. An integrated systems-based approach such as this has the potential to facilitate a change in urban areas, from 'water-wasteful' to 'water-sensitive' settlements, where a 'settlement' is to be broadly understood as comprising a concentration of people within a specific area and serviced by some public infrastructure and services.

The notion of a Water Sensitive City (WSC), a 'city' where water is given due prominence in the design of urban areas, was first proposed by Brown *et al*. (2008) at the 11th International Conference on Urban Drainage. As part of this vision Brown *et al*. (2009) put forward a conceptual framework for visualising and 'benchmarking' the evolution towards a WSC through the adoption of what the Australians termed Water Sensitive Urban Design (WSUD). Whilst the Brown *et al*. (2009) vision for WSCs is relevant to RSA and may assist in addressing some of the challenges facing the country's water sector, the framework in its current form needs to be contextualised for the unique development challenges RSA is facing. This study is thus aimed at providing strategic guidance to urban water management decision-makers (primarily city managers and other local authority officials) on the use of WSUD in a South African context. It introduces the philosophy of WSUD – a new paradigm in urban water management – and starts to build the case for its adoption in a water-scarce country such as RSA, as well as providing a base for future studies. It attempts to define what 'water sensitivity' might mean within the RSA context – including expanding the definition of 'city' in WSC to include a broader range of settlement types – so as to motivate for adopting a context-specific vision for water sensitivity. In this regard it suggests a strategic framework with four different components to enable the transformation to Water Sensitive Settlements

(WSS) in RSA, and provides guidance on the various WSUD strategies that could be adopted to achieve this, as well as giving an indication of appropriate modelling tools. A policy review (including institutional and legal issues) was also carried out in order to identify obstacles to WSUD and to provide recommendations on how they may be overcome.

Water sensitive settlements in a developing country context – 'transforming our cities'

Water sensitivity in RSA is defined as the management of the country's urban water resources through the integration of the various disciplines of engineering, social and environmental sciences – whilst acknowledging that: RSA is water scarce; access to adequate potable water is a basic human right; the management of water should be based on a participatory approach; water should be recognised as an economic good; and water is a finite and vulnerable resource, essential to sustaining all life and supporting development and the environment at large. A *Water Sensitive Settlement* (WSS) is thus one where water is managed and treated in a manner which reflects the principles of water sensitivity. Historically, water systems have been developed using a linear design approach, i.e. source, treat, transport, distribute, collect, treat and dispose. This technologically-driven and resource-intensive approach is removed from the citizens it serves, resulting in technocratic solutions and the fragmentation of the management of the urban water cycle. WSSs require a cyclical, systems approach which, in simple terms, assumes that everything in the world is connected.

WSUD has the potential to: mitigate the negative effects of water scarcity; manage and reverse water pollution; develop social and intergenerational equity; increase sustainability; and develop resilience within water systems in RSA. In particular, it could transform the extremely divided settlements that are so typical of the country into ones where water can be used to connect disparate communities and bring about significant change. The adoption of WSUD requires a proactive and holistic approach that is able to comprehend the consequences of such a transition and thereby to help overcome socio-economic barriers whilst simultaneously producing sustainable and equitable economic growth, and protecting scarce natural resources. Implementing WSUD in RSA thus requires consideration of a number of issues, including:

i) *Institutional structures:* The fragmented 'silo-management' of different aspects of the urban water cycle occurs, in part, because of the allocation of different responsibilities to different municipal departments; e.g. stormwater management is often undertaken by roads departments, whilst water supply is separated from sewage collection, treatment and disposal. This has resulted in poor communication and integration of services.

ii) *Champions:* Identifying and supporting champions will likely be essential to introducing and embedding a WSUD approach in RSA.

iii) *Equity:* Includes dignity, ownership and respect. RSA already faces challenges in the delivery of services to the previously disadvantaged. Attempting to do this in a 'green' or water sensitive manner adds another layer of complexity. It will be difficult for the government to implement 'green' projects when basic services do not exist, unless these are accomplished simultaneously.

iv) *Health aspects:* Potential health risks must be taken into account, particularly in respect of the creation of different pathways (mainly waterborne) for spreading disease.

v) *Adaptability & uncertainty:* RSA has technical capacity and skills constraints at local and national government level so overly complex technologies should be avoided. Uncertainties relating to the impacts of climate change, politics, demographics and resulting water demand patterns also result in policy makers being risk-averse.

vi) *Mitigation:* RSA needs to manage its environmental impacts, particularly in terms of CO_2 outputs resulting from energy usage (i.e. adopting WSUD to avoid desalination).

vii) *Ecosystem Goods & Services (EGS):* Whilst the economic valuation of ecosystem services is recognised worldwide as a means of motivating for the adoption of the WSUD approach, it is unlikely to have as much impact in RSA given the widespread poverty and inequality in the country. For example, politicians are more likely to consider job creation opportunities and the ability of WSUD to deliver services quickly, while city officials would be more interested in issues of cost and maintenance requirements, appropriateness. It is thus necessary to consider the likely areas of interest / opportunities for the various target audiences and stakeholders in RSA.

Terminology

The WSUD approach as proposed by Brown *et al*. (2008) is defined as "*an approach to urban planning and design that integrates land and water planning and management into urban design. WSUD is based on the premise that urban development and redevelopment must address the sustainability of water*" (Engineers Australia, 2006). There are a number of different terms and concepts embedded in this definition of WSUD. Throughout the framework development process for RSA, terminology was found to be crucially important. Definitions from literature were often found to be inappropriate or lacking for the RSA context – for example, the WSUD approach as originally envisaged does not take cognisance of the 'developmental' or 'equity' issues which are so prevalent in developing countries, and especially pronounced in RSA as a result of the country's apartheid legacy. For example, it will be difficult for urban development and redevelopment to "*address the sustainability of water*" in a nation such as RSA where a substantial proportion of the population still do not have access to basic water supply or sanitation. Thus, while in principle 'leapfrogging' through developmental states is the ideal, there are social (equity) and practical issues that need to be considered. These issues are often associated with the terminology and are specific to each context. As a result the critical terms are defined for RSA as follows:

- *Urban design and planning* – whilst the terms urban design and urban planning are intrinsically linked, in the RSA context urban planners generally undertake planning (which is very often site-focused and does not consider the broader system); whilst engineers, architects, landscape architects and scientists undertake design. If the objective of WSUD is to produce sustainable development, however, urban planning should be seen as the technical, iterative process which is used to guide and set the design for an appropriate urban form, i.e. it considers the 'bigger picture'; while urban design refers to the local design (or form) of an area, and should fit in with existing urban plans.

- *Urban management* – Urban management entails operational and maintenance aspects, community awareness building and education, optimisation of the use of resources, and the identification of infrastructure needs emanating from the planning process.

With this in mind, and after extensive consultation with stakeholders, the term WSUD was split into three components, to be considered in an integrated manner towards the achievement of WSSs (as defined previously); i.e. *Water Sensitive Urban Design, WSUD* (ensuring 'urban design' is undertaken in a 'water sensitive' manner); *Water Sensitive Urban Planning, WSUP* (high-level urban planning and governance); and *Water Sensitive Urban Management, WSUM* (management of infrastructure supporting the urban water cycle).

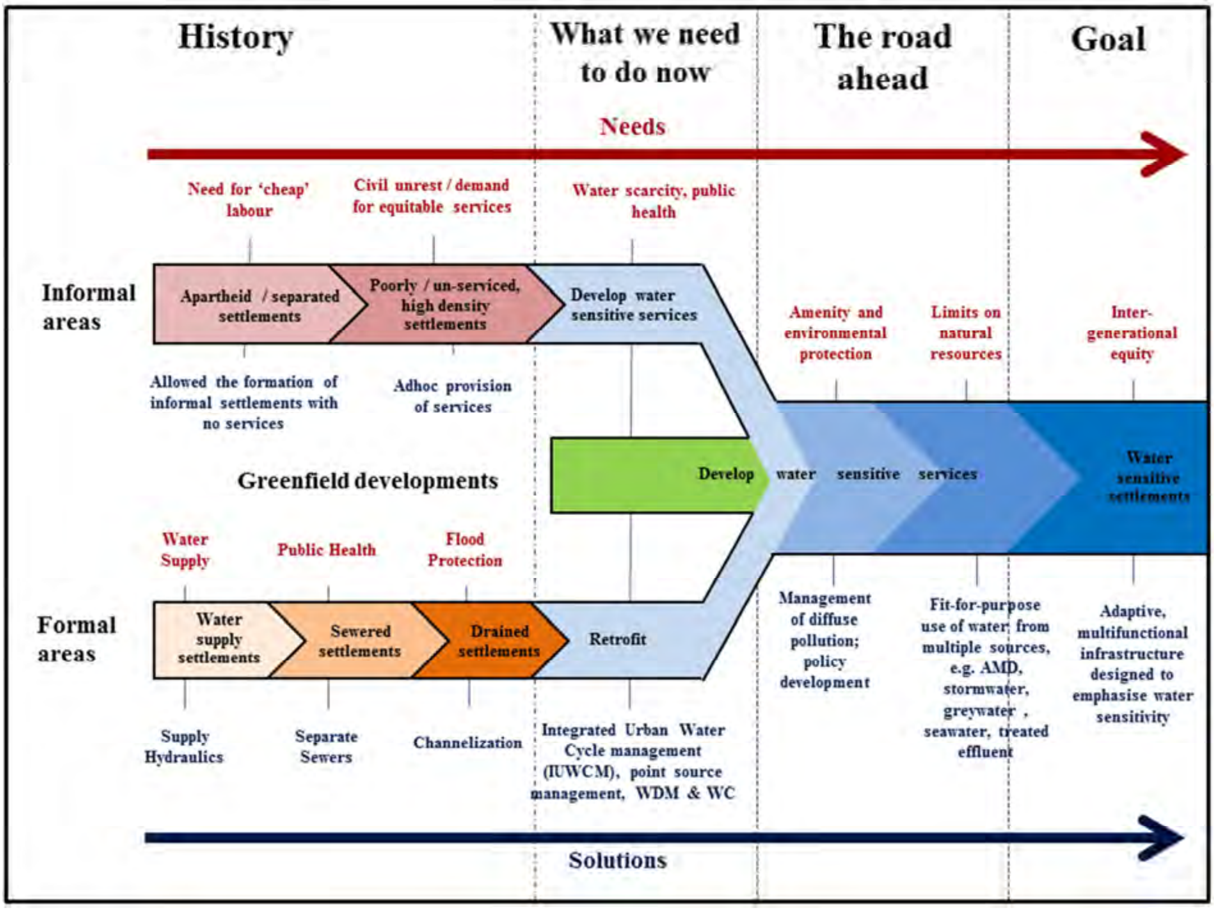
Developing the WSUD framework for South Africa

The management of water occurs within a highly complex and multi-constrained social-ecological-political-economic context, and requires a clear recognition of how the various stakeholders might work collaboratively to address the range of water security concerns that the country faces. The development of the WSUD framework for RSA was therefore undertaken using a Learning Alliance; "*platforms that bring together stakeholders from a range of institutions...to think, act and learn together, using action research to test ideas*" (Butterworth *et al*., 2011) approach, where input could be obtained from as many participants as possible through a series of workshops as well as individual interviews with officials from four of the major metropolitan municipalities in RSA. Academic disciplines included, *inter alia*, civil engineers, social anthropologists, environmental scientists, urban planners, political scientists, landscape architects, urban ecologists and hydro-geologists. The framework that was developed has four complementary components as follows:

i) *Research component:* On-going research, as well as capacity building, is needed to develop RSA-relevant guidelines for the realisation of WSSs. The notion of '4T' (tools, transfer, tactics and trials) was thus conceptualised as a useful, cyclical strategy to support the promotion and adoption of WSUD. It includes the ongoing development of tools (manuals, guidelines, etc.), transfer of knowledge to appropriate officials, application of tactics for encouraging WSUD implementation (such as getting new policies written), and testing through trials (pilot studies, small scale developments, etc.).

ii) *Vision component:* The Brown *et al*. (2009) urban water management transitions framework details the critical states through which cities move as they aim to become more sustainable. It identifies six transition states and their associated socio-political drivers and service delivery functions and is used to underpin the development of policy and to benchmark a city's progress (either forwards or backwards) at a macro scale. As a result of being envisaged mostly for cities in the developed world, it does not take into account the impact of a number of uniquely RSA factors; it was thus adapted for the RSA context as shown in the figure below. Brown *et al*. (2009) describe the transitions for formal settlements in detail; most formally-developed areas in RSA cities would fit their description of 'drained cities'.

If RSA wishes to transition towards WSSs in line with current international best practice, the legacy of apartheid – significant backlogs in infrastructure (i.e. poorly-serviced informal settlements) which the government is attempting to address – will need to be recognised. Any attempt to transition to WSSs will need to consider both formal areas, as well as the informal settlements where high densities and limited infrastructure are common. The burden, benefits and responsibility of and towards implementing WSUD, and thus achieving WSSs, has to be borne by all residents in both formal and informal areas so that they can simultaneously and equitably transition.



Framework for Water Sensitive Settlements in RSA, *"Two histories, one future"*
(adapted from Brown *et al*., 2009)

iii) *Implementation component.* The various aspects required for managing the transition towards WSSs are: policy development; institutional structures; community participation; construction of infrastructure; and operation and maintenance. The most important consideration in RSA is how to effect a transition in the context of limited resources – both human and financial. It would be unreasonable to expect a municipality with limited funding and capacity to retrofit all of its urban water systems. Using the analogy of Maslow's hierarchy of needs (Maslow, 1943), municipalities need to ensure that they are at least meeting the physical water needs of their residents whilst attempting to provide services which help transition to the ultimate goal water sensitive settlements. A municipality cannot be expected to focus on establishing ecosystem sustainability and intergenerational equity unless it can simultaneously provide adequate and safe water to its citizens. Where it is not possible to incorporate the principles of water sensitivity (for example, the emergency provision of water services), municipalities should target their initiatives with the underlying philosophy of: 'Do what you can with what you have'; i.e. begin by strengthening local legislation and regulations to encourage this transition.

iv) *Narrative component*: Narratives "*… simplify and offer a stable vision and interpretation of reality and are able to rally diverse people around particular story lines*" (Molle, 2008). This narrative expresses why a WSS is needed; how it can be implemented; and what the outcome should be. The WSS narrative for RSA has been developed to tie together the other three components of the framework, so that at the very least all stakeholders should understand and engage with the idea of a WSS as follows:

Why?

"*…mitigating water scarcity, improving water quality, thereby protecting ecosystems, through the development of water sensitive urban areas (for all) that are sustainable, resilient and adaptable to change, while simultaneously being a place where people want to live…*"

Result!

How?

Relating WSUD to development planning in South Africa

The various existing development plans and strategies within the different sectors related to urban water need to be aligned to ensure that they are aimed towards a common goal of decoupling future economic growth from resource consumption. Two important documents have recently been released in RSA to guide management of the water sector in this regard – the National Development Plan (NDP), issued by the National Planning Commission (RSA, 2011b) with the aim of setting an overarching plan to eliminate poverty and reduce inequality, and the National Water Resource Strategy 2 (NWRS-2), published by the Department of Water Affairs (DWA, 2013). WSUD has the potential to act as the mechanism to address – and enhance – the objectives of the NDP and NWRS-2, and the Framework for Water Sensitive Settlements in RSA will show how this can be achieved. The Framework could be adopted as a means of meeting the challenges facing the urban water management sector, and achieving the goals of the NDP and the NWRS-2 with respect to urban areas in RSA.

Both the NWRS-2 and the NDP propose the adoption of 'developmental water management' (DWM), where water plays a critical role in equitable social and economic development and where Government has a critical role in ensuring that this takes place (DWA, 2013). Despite these documents having similar visions and acknowledging that RSA is a water stressed country, water resources are still not receiving the priority status and attention they deserve (DWA, 2013). The NWRS-2 and the Framework both note that by adopting a more holistic approach towards water availability, use and management, water resources can be defined in a much broader context. This will however require that the NWRS-2 is developed further and implemented with strong scientific support, good social dynamics analysis and innovative technological and systems solutions (Naidoo, 2013). An increased emphasis on the creation of water sensitive settlements is inevitable, and as such, the following aspects need to be considered further:

- *Water resources & Total Water Cycle Managemen*t – the consideration of water use efficiency, demand management, improved water governance, optimisation of existing water resources including groundwater, seawater, rainwater harvesting, re-use of water, and resource protection and groundwater recharge is required if RSA is to have adequate water resource potential to meet its requirements (DWA, 2012). The WSUD approach encourages water management authorities to find 'fit for purpose' solutions that recognise the importance of the total water cycle and its impacts on other sectors.
- *Economics* – part of achieving a WSS is an economic assessment of the provision of water services, and an evaluation of the secondary economic benefits (including ecosystems services) that could accrue from the implementation of such an approach.
- *Water-Energy-Food Nexus* – the 'fit for purpose' approach to water management that is central to WSS and WSUD could balance the need to ensure water, food and energy security with the need for social development – whilst acknowledging the potential health risks. WSUD also aims to take advantage of ecosystem goods and services by 'greening' cities, which provides the additional advantage of reducing the heat island effect, resulting in a reduction in energy consumption for cooling.
- *Climate change / resilience* – a WSUD approach encompassing integrated planning at a macro-level will ensure that the risks associated with climate change impacts are better understood and the necessary institutional responses can then be put forward. Municipal authorities need to go beyond the delivery of basic services to ensure urban resilience by, *inter alia*, reconfiguring cities by way of strategic planning and investment to address future uncertainties like resource shortages, flood risks and climate change impacts.
- *Capacity building* – The NDP, NWRS-2 and Framework all agree that there is a need to develop capacity if RSA is to implement any of these strategies. The NWRS-2 further identifies that the successful implementation of the strategy will depend on, *inter alia*,

gathering adequate and reliable information; adhering to adopted policies and procedures; and the deployment of appropriately skilled people.

Institutional considerations

As part of this study an investigation of the institutional arrangements with respect to WSUD in selected South African metropolitan governments was undertaken with the objective of translating the need for the physical imperatives of urban planning for sustainable water resource management into an assessment of the institutional arrangements that either facilitate or impede co-ordination and integration. The enablers and obstacles were assessed by examining the institutional arrangements that metro governments in South Africa have put in place to render urban planning, the various technical services involved in the delivery, storm and wastewater management, as well as environmental management services.

The formal organisational arrangements in the four metropolitan municipalities of Cape Town, eThekwini, Johannesburg and Tshwane were assessed to determine how urban water systems are managed in these cities. The assumption that both core (e.g. supply, storm and wastewater) and ancillary (e.g. environmental management) urban water management functions are currently being 'compartmentalised' was confirmed in all four metros, albeit with some notable differences. In general, stormwater management is paired with roads and transport, which operates separately from the supply and treatment of water, which is typically housed in a department of water and sanitation.

Whilst there is evidence of municipalities responding to individual WSUD principles, this does not necessarily translate into corresponding levels of co-ordination and integration across water and other related services (such as Planning, Urban Design, Housing, etc.) within these cities. It was also evident that there was unrealised potential for more extensive co-ordination, which could be facilitated by urban and strategic planning fora. Despite some concrete efforts towards more extensive co-ordination, driven largely by the stormwater and environmental management portfolios, a number of constraints continue to impede their full potential – including a lack of enabling council-approved policy and guidelines (with political backing and the force of by-laws), and the need for interventions to effectively re-train (capacity-build) technical officials on water sensitive approaches. This reinforces the need for policy advocacy of SuDS and WSUD at an executive level, which could also facilitate political backing. In this regard, it may be more effective for metros to push WSUD as part of complementary initiatives that have greater and wider public and policy appeal, such as 'greening' initiatives which promote energy efficiency, as well as climate change mitigation.

Conclusions and recommendations

Whilst service delivery and social upliftment are high on the South African political agenda, the challenge is to promote economic and social equity whilst simultaneously ensuring environmental sustainability, particularly in urban areas. It is postulated that from a water management perspective, this will require the adoption of WSUD in an attempt to achieve the ultimate goal of WSSs, and it is only through the effective integration of urban design, planning and management undertaken in a water sensitive manner that this goal will be realised.

The NDP and NWRS-2 set broad strategies and ambitious goals for the development of a desirable future for RSA and for managing the water resources of the country at a catchment scale, through the implementation of catchment management agencies. They do not deal with nor set a vision for the management of water within an urban setting however. The four-component (vision, research, narrative and implementation) framework that has been developed as part of this research focuses specifically on urban water management and sets a vision for transforming RSA's towns and cities to be water sensitive in line with the ideals of both the NDP and NWRS-2. The research component can be used to build the knowledge and capacity required to adopt the long-term vision, while the narrative sets the scene for engaging with stakeholders. The implementation component addresses the trade-offs that may be required in determining the best use of resources for developing multi-functional urban areas that are resilient and adaptable to change, as well as addressing development and equity issues. Together the NDP, NWRS-2 and framework could provide a comprehensive vision for the future management of water resources in RSA.

The adoption of an approach like WSUD has the potential to bring about a positive change in urban areas in many ways, e.g. lowering temperatures in respect of climate change adaptation and mitigation. Conserving potable water resources also means that there will be water available for other productive uses; this has socio-economic implications and ensures greater equity in terms of the availability of a wider variety of water services. In the South African context, where cities have largely been shaped by the legacy of apartheid, WSUD also has the potential to 'connect' spatially-divided communities and settlements through linking open spaces and promoting these spaces to showcase water; providing blue-green infrastructure; and creating 'liveable' cities. WSUD also offers a host of options for new innovations, techniques and technologies which could offer potential for the commercialisation of products, thereby enhancing job creation and contributing to the green economy. However, engineers and technologists can only take the notion of WSS so far – sociological, planning and urban design aspects must also be included. It is postulated that if the required planning is achieved at an overarching level, then WSUD will automatically be incorporated. A useful question is "How can the WSUD philosophy be used to integrate water into urban design so as to bring about fundamental change in South African communities?" This will only be progressively answered once there are sufficient South African case study examples to support the changing paradigm in urban water management from 'business as usual' to one where cities can effectively be transformed.

It is important that the profile of WSUD and SuDS is increased amongst the engineering fraternity, as well as with national and local government officials, planners, developers, etc. One of the ways of ensuring this is to establish Learning Alliances (LAs) in different towns / cities in order to link the various stakeholders in these urban water systems and promote shared learning and innovation around sustainable water management practices. Skilled facilitators will be required to assist in the effective running of these LAs and to ensure the resultant outcomes in terms of policy and impacts. Another way of disseminating information on WSUD would be to develop a hands-on, practical manual on how to bring WSUD into existing and new developments

PART 2: WSUD Guidelines

The overarching theme of WSUD is ecologically sustainable development; by considering all aspects of the water cycle and their interaction with urban design, it aims to be the medium through which sustainable urban water management is achieved. WSUD comprises two main functions – urban water infrastructure, and the design & planning process associated with this. However, the report does not deal in detail with the design and planning aspects of the WSUD approach, but rather provides illustrations of the types of infrastructure-related activities that can be implemented as part of WSUD, including:

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

Currently these aspects of urban water management are largely dealt with separately by different professionals – if they are considered at all – however the holistic approach propounded by WSUD requires that they be considered simultaneously. There are a wide range of urban water infrastructure activities which can be used to effectively incorporate WSUD into planning and design. These strategies adopt a variety of Best Management Practices (BMPs) and Best Planning Practices (BPPs) to fulfil the objectives of total water cycle management (Water by Design, 2009). It should be noted that the four streams of the urban water cycle (stormwater, wastewater, groundwater and water supply) are intricately linked; different technologies and activities apply to each of the streams with several applying to one or more of the streams. The ultimate goal is the holistic management of the urban water cycle to simultaneously achieve the desired economic, environmental, and social benefits.

Further information on urban water infrastructure activities which incorporate WSUD aspects can be found in several well-documented and researched manuals and guidance documents which have been published internationally in recent years.

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Appendix A: International examples of WSUD implementation

Appendix B: Institutional review

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Abbreviations

AMD	Acid Mine Drainage
ASR	Aquifer Storage and Recovery
ASTR	Aquifer Storage, Transfer and Recovery
BMP	Best Management Practice
BPP	Best Planning Practice
CMA	Catchment Management Agency
CoCT	City of Cape Town
CoF	City of the Future
DWA	Department of Water Affairs
DWM	Developmental Water Management
EGS	Ecosystem Goods & Services
ERT	Electrical Resistive Tomography
GI	Green Infrastructure
GRPP	Green Roof Pilot Project
IDF	Integrated Development Framework
IUWM	Integrated Urban Water Management
IWA	International Water Association
IWRM	Integrated Water Resource Management
LA	Learning Alliance
LCCA	Life Cycle Cost Analysis
LID	Low Impact Development
LIUDD	Low Impact Urban Design and Development
MAR	Managed Aquifer Recharge
NA	Natural Assets
NDP	National Development Plan
NEMA	National Environmental Management Act
NRW	Non Revenue Water
NWA	National Water Act
NWP	National Water Policy

NWRS	National Water Resource Strategy
NWSA	National Water Services Act
O&M	Operation and Maintenance
RSA	(Republic of) South Africa
SEM	SuDS Economic Model
SuDS	Sustainable (urban) Drainage Systems
SWITCH	Sustainable Water management Improves Tomorrow's Cities Health
TEV	Total Economic Value
TMG	Table Mountain Group
UCT	University of Cape Town
WC/WDM	Water Conservation / Water Demand Management
WRC	South African Water Research Commission
WSA	Water Services Authority
WSC	Water Sensitive City
WSDP	Water Services Development Plan
WSP	Water Services Provider
WSS	Water Sensitive Settlements
WSUD	Water Sensitive Urban Design
WSUM	Water Sensitive Urban Management
WSUP	Water Sensitive Urban Planning
WUA	Water Users Association
WWTP	Wastewater Treatment Plant

Glossary of terms

Please note that these definitions apply to the use of terms in this document only.

Aerobic is the state requiring or allowing the presence of free essential oxygen.

Anaerobic is the absence of free elemental oxygen, or a state not requiring or damaged by the absence of free elemental oxygen.

Aquifer is a porous, water-logged sub-surface geological formation. The description is generally restricted to media capable of yielding a substantial supply of water.

Aquitard is a water-saturated sediment or rock whose permeability is so low (usually owing to a layer of clay, silt, or rock) that it cannot transmit any useful amount of water.

Attenuation means the reduction of peak stormwater flow.

Bio-retention area here refers to a depressed landscaped area that collects stormwater runoff and infiltrates it into the soil below through the root zone thus prompting pollutant removal.

Brownfield here refers to a site that is or was occupied by a permanent structure which is now being considered for redevelopment.

Catchment here refers to the area contributing runoff to any specific point on a watercourse or wetland.

Channel here refers to any natural or artificial watercourse.

Climate change is a continuous phenomenon and refers to the change in global climatic conditions, e.g. as a result of temperature increases due to anthropogenic emissions.

Contamination here refers to the introduction of microorganisms, factory produced chemicals or wastewater in concentrations that render water unsuitable for most uses.

Denitrification is the biological conversion of nitrate to nitrogen gas, nitric oxide or nitrous oxide**.**

Detention pond here refers to a pond that is normally dry except following large storm events when it temporarily stores stormwater to attenuate flows. It may also allow infiltration of stormwater into the ground.

Drainage may refer to: (1) the removal of excess ground-water or surface water by gravity or pumping; (2) the area from which water bodies are removed; or (3) the general flow of all liquids under the force of gravity.

Drainage area is that part of a catchment that contributes to the runoff at a specified point.

Drainage system refers to the network of channels, drains, hydraulic control structures, levees, and pumping mechanisms that drain land or protect it from potential flooding.

Dry pond is a detention pond that remains dry during dry weather flow conditions.

Dry weather flow means flow occurring in a water course not attributable to a storm rainfall event. Dry weather flows do not fluctuate rapidly.

Effluent here refers to wastewater that flows from a process or confined space that has been partially or completely treated.

Evapotranspiration means the evaporation from all water, soil, snow, ice, vegetation and other surfaces plus transpiration of moisture from the surface membranes of leaves and other plant surfaces.

Filtration, also referred to as **biofiltration**, means the filtering out of stormwater runoff pollutants that are conveyed with sediment by trapping these constituents on vegetative species in the soil matrix or on geotextiles.

Flood means a temporary rise in water level, including ground water or overflow of water, onto land not normally covered by water.

Floodplain means the area susceptible to inundation by floods.

Green roof is a roof on which plants and vegetation can grow. The vegetated surface provides a degree of retention, attenuation, temperature insulation and treatment of rainwater.

Greenfield here refers to any site including parkland, open space and agricultural land which has not previously been used for buildings and other major structures.

Hydrology refers to the physical, chemical and physiological sciences of the water bodies of the earth including: occurrence, distribution, circulation, precipitation, surface runoff, stream-flow, infiltration, storage and evaporation.

Impervious surface here refers to surfaces which prevent the infiltration of water. Roads, parking lots, sidewalks and rooftops are typical examples of impervious surfaces in urban areas.

Infiltration here refers to the process of penetration of rainwater into the ground.

Infiltration device is a SuDS element designed to aid the infiltration of surface water into the ground.

Non-revenue water refers to all water lost through physical leakage or commercial losses(meter under-reghistration, billing errors, theft, etc.) as well as any unbilled autorised consumption (fire-fighting, mains flushing, etc.).

Permeability refers to the ability of a material to allow water to flow through when fully saturated and subjected to an unbalanced pressure.

Peak discharge (also known as ‘peak flow’) is the maximum rate of flow of water passing a given point during or immediately after a rainfall event.

Precipitation is the water received from atmospheric moisture as rainfall, hail, snow or sleet, normally measured in millimetres depth.

Rainwater harvesting is the direct capture of stormwater runoff, typically from roof-tops, for supplementary water uses on-site.

Receiving waters are natural or man-made aquatic systems which receive stormwater runoff, e.g. watercourses, wetlands, canals, estuaries, groundwater and coastal areas.

Resilience refers to the preservation or enhancement of adaptive capacity, i.e. the capacity of a system to preserve core functioning in the presence of shocks and long-term changes.

Retrofitting here refers to the modification or installation of additional or alternative stormwater management devices or approaches in an existing developed area in order to achieve better management of stormwater.

Runoff generally refers to the excess water that flows after precipitation.

Sedimentation is the deposition of soil particles that have been carried by flowing waters, typically during flood peaks as a consequence of a decrease in the velocity of flow below the minimum transportation velocity.

Soakaway is a subsurface structure that is designed to promote infiltration into the ground.

Source controls are non-structural or structural best management practices to minimise the generation of excessive strormwater runoff and/or pollution of stormwater at or near the source.

Stormwater is water resulting from natural precipitation and/or accumulation and includes rainwater, groundwater and spring water.

Stormwater runoff refers to the portion of rainfall which flows to the surface drainage system.

Stormwater system is constituted by both constructed and natural facilities including: stormwater pipes, canals, culverts, overland escape routes, ‘vleis’, wetlands, dams, lakes, and other watercourses, whether over or under public or privately owned land, used or required for the management, collection, conveyance, temporary storage, control, monitoring, treatment, use and disposal of stormwater.

SuDS is the abbreviation for sustainable drainage systems or sustainable urban drainage systems, which are a sequence of management practices and/or control structures or technologies designed to drain surface water in a more sustainable manner than conventional techniques.

Surface runoff is that part of the runoff that travels over the ground surface and in channels to reach the receiving streams or bodies of water.

Sustainable development can be considered as “*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED, 1987).

Swale is a shallow vegetated channel designed to convey stormwater, but may also permit infiltration. The vegetation assists in filtering particulate matter.

Treatment train is a combination of different methods implemented in sequence or concurrently to achieve best management of stormwater. These methods include both structural and non-structural measures.

Unconfined aquifer is an aquifer that is open to receive water from the surface.

Vadose zone is the portion of the earth between the land surface and the groundwater table (otherwise known as the unsaturated zone). In this zone, pore spaces are filled with water and air.

Volatilisation is the conversion of water (stormwater / groundwater) compounds to gas or vapour typically as a result of heat, chemical reaction, a reduction of pressure or a combination of these.

Water table is the upper most level of the zone of saturation below the Earth's surface, except where this surface is formed by an impermeable body.

Watercourse means any river, stream, channel, canal or other visible topographic feature, whether natural or constructed, in which water flows regularly or intermittently including any associated storage and/or stormwater attenuation dams, natural vleis or wetland areas.

Watershed is the upper boundary of a specified catchment area for rainfall that contributes to a given drainage area.

Wetland refers to any land translational between terrestrial and aquatic systems where the water table is usually at or near the surface, or is periodically covered with shallow water, and which in normal circumstances supports or would support vegetation typically adapted to life in saturated soil. This includes water bodies such as lakes, salt marshes, coastal lakes, estuaries, marshes, swamps, ‘vleis’, pools, ponds, pans and artificial impoundments.

PART 1

WSUD framework for South Africa

Preamble

This report is not meant to be a prescriptive ‘manual’ on the concept of Water Sensitive Urban Design (WSUD), but is rather a strategic document aimed at providing a context-specific framework and guidance relating to a new way of thinking about urban water management in South Africa. WSUD represents a policy amalgam which reflects a paradigm shift in the way urban environments are planned and designed such that issues of water sustainability and environmental protection are considered (Wong, 2006a). The document is therefore intended to be pitched at a broad audience, and will serve as an introduction to this new approach. It is likely to form the foundation for future research and policy development in the integration of water cycle management into planning and design for the growth and development of water sensitive settlements in South Africa.

1. Introduction and background

The adequate provision of basic services – including water – to South Africa's citizens is one of the most significant challenges facing the country, and is felt most strongly in the rapidly growing urban areas. According to Census 2011, more than 63% of the South African population already live in urban centres – which include a wide spectrum of settlement types, from small towns with a population of 15 000 to large cities and metros with populations of many millions (StatsSA, 2012). It is estimated that the proportion of urban dwellers in the country will increase to over 70% by 2030, and could reach 80% by 2050 (COGTA, 2013). In this context of rapid urbanisation, water security is a major concern, particularly since climate change has the potential to worsen systemic water shortages over the medium to long term. South Africa (RSA) is already "… *severely constrained by low rainfall, limited underground aquifers, and reliance on significant water transfers from neighbouring countries*" (Barilla Group *et al*., 2009). Moreover, most surface water resources are already fully accounted for, and consequently the country could face an average supply deficit of 17% between projected demand and supply by 2030, with some catchments predicted to face deficits of almost 40% (*ibid*). Added to the problem of significant resource shortages is the growing burden of wastewater generated by both the burgeoning population and by the increasing demands of the resource-based industrial sector; compromised water treatment leading to increased pollution of surface and ground water; and complex as well as fragmented institutional structures. A legacy of general disregard for the value of water – both economic and socio-cultural – has compounded these problems (DWA, 2012). The deteriorating quantity and quality of RSA's water resources is particularly problematic as these systems support the environmental ecosystem and affect reliable production of food and energy, all of which are critically important for the country's social and economic development. Effective management of existing water systems is thus crucial in efforts to address concerns with water availability in the future and the likely impacts of water availability and quality on sustainable growth – this is exemplified in the World Bank report on "The future of water in African cities" (Jacobsen *et al*., 2013).

It is evident that alternative, systems-based approaches to conventional water management of water supply and modes of ensuring water quality are required. New models of water capture, provision, treatment and governance need to be explored and developed to improve and enhance the effectiveness of interaction between the multiple actors who determine water use. A systems approach with multiple objectives is called for; one that takes into account community values and aspirations when dealing with water supply, wet and dry sanitation, biological and chemical treatment of associated contaminants, drainage and the management of industrial effluents, whilst also acknowledging the range of users, including: residential, institutional, commercial and industrial. An integrated systems-based approach such as this has the potential to facilitate a change from 'water-wasteful' to 'water-sensitive' urban areas.

The notion of a Water Sensitive City (WSC), a 'city' where water is given due prominence in the design of urban areas, was first proposed by Wong & Brown (2008) and Brown *et al*. (2008) at the 11th International Conference on Urban Drainage. As part of this vision Brown *et al*. (2009) put forward a conceptual framework for visualising and 'benchmarking' the evolution towards a WSC through the adoption of what the Australians termed Water Sensitive Urban Design (WSUD). Whilst the Brown *et al*. (2009) vision for WSCs is relevant to RSA and may assist in addressing some of the challenges facing the country's water sector through promoting innovative water management approaches aimed at establishing resilient settlements, the framework in its current form needs to be contextualised for the unique development challenges RSA is facing.

It was with this in mind that in 2011 the South African Water Research Commission (WRC) solicited research proposals aimed at providing guidance to urban water management decision-makers on the use of WSUD in a South African context. The research was designed to follow on from and extend WRC Project no. K5/1826, 'Alternative technology for stormwater management' (Armitage *et al*., 2013), which focused specifically on providing guidelines for the implementation of Sustainable Drainage Systems (SuDS) in South Africa. The new project (this one) was to link SuDS to the larger issues of water management in urban areas. The main aims for the research were as follows:

i) To develop a strategic framework for sustainable urban water management / WSUD in South Africa.

ii) To carry out an institutional, legal and policy issue review with a view to identifying obstacles to WSUD and providing recommendations on how they may be overcome.

iii) To develop WSUD guidelines for South Africa.

iv) To identify appropriate modelling tools for WSUD in South Africa.

It should be noted that the research mainly took the form of a desk-top study with a focus on engaging with the relevant stakeholders in local government and synthesising and analysing the existing literature on WSUD for a developing nation context. Time and budgetary constraints did not allow for a full case study analysis of the potential for WSUD in RSA; it is envisaged that a detailed catchment study will form part of the follow-on research to this one. This report rather introduces the philosophy of WSUD and is an attempt to start building the case for its adoption in a water-scarce country such as RSA. It is aimed at defining what 'water sensitivity' might mean within the RSA context – including expanding the definition of 'city' in WSC to include a broader range of settlement (broadly understood as comprising a concentration of people within a specific area and serviced by some public infrastructure and services) types – so as to motivate for adopting a context-specific vision for water sensitivity. In this regard it suggests a framework with four different components that has been developed to enable the transformation to Water Sensitive Settlements (WSS) in RSA.

2. A changing paradigm

The term Water Sensitive Urban Design (WSUD) was first coined in the early 1990s in response to severe challenges relating to water quantity, quality and drainage in Western Australia, and the inaugural Conference on WSUD was held in Australia in 2000 (BMT WBM, 2009). The international Working Group on WSUD was formed by the IWA/IAHR Joint Committee on Urban Drainage at their Triennial Conference in Copenhagen in 2005. However, it was never intended that urban drainage should be the main driver for WSUD. Instead, the hope was always that a more water-sensitive approach to the design of cities and its infrastructure would be embedded into normal city planning and service delivery, resulting in a more sustainable environment. In this regard, WSUD is not so much a collection of technologies as a philosophy that sees the need to design and manage urban areas in a water sensitive manner. According to Wong (2006a), the term Water Sensitive Urban Design (WSUD) *"… reflects a new paradigm in the planning and design of urban environments that is sensitive to the issues of water sustainability and environmental protection. The term comprises two parts: 'Water Sensitive' and 'Urban Design'. Urban Design is a well-recognised field associated with the planning and architectural design of urban environments, covering issues that have traditionally appeared outside of the water field but nevertheless interact or have implications to environmental effects on land and water. WSUD brings 'sensitivity to water' into urban design, i.e. it aims to ensure that water is given due prominence within the urban design processes. The words 'Water Sensitive' define a new paradigm in integrated urban water cycle management that integrates the various disciplines of engineering and environmental sciences associated with the provision of water services including the protection of aquatic environments in urban areas. Community values and aspirations of urban places necessarily govern urban design decisions and therefore water management practices. Collectively WSUD integrates the social and physical sciences. WSUD pertains to the synergies within the urban built form (including urban landscapes) and the urban water cycle (as defined by the conventional urban water streams of potable water, wastewater and stormwater). WSUD may thus be viewed as integrating the holistic management of the urban water cycle into the planning and design of the built form in an urban environment."*

2.1 'Cities of the Future'

The emerging view across professional disciplines (e.g. engineering, environmental science, planning, and architecture) is that the current infrastructure paradigm which relies on fast surface and underground conveyance of water and wastewater, decentralised wastewater management systems, and the inefficient use of energy and other resources in cities, has become an impediment to sustainable urban development, especially in the context of the impacts of climate change (Novotny *et al.*, 2010; Jacobsen *et al*., 2013). The inclusion of environmental considerations in planning processes is seen as a necessity in what is termed the 'City of the Future' (CoF). This represents a major shift in the way new urban settlements will be developed or in the retrofitting of existing ones to achieve sustainability. In particular there is a need to change the linear urban metabolism patterns (where resources such as water, food, energy, materials and chemicals are delivered, metabolised and changed to waste outputs) to cyclical ones that re-use resources (*ibid*).

The International Water Association (IWA) Cities of the Future programme was officially launched at Stockholm World Water Week in August, 2009, and the IWA World Water Congress held in Canada in 2010 culminated in the draft Montréal declaration on CoF which was tabled in order to "*ensure that all IWA activities contribute to the achievement of sustainable, resilient and liveable cities of the future*" (IWA, 2010). Several actions were highlighted as follows:

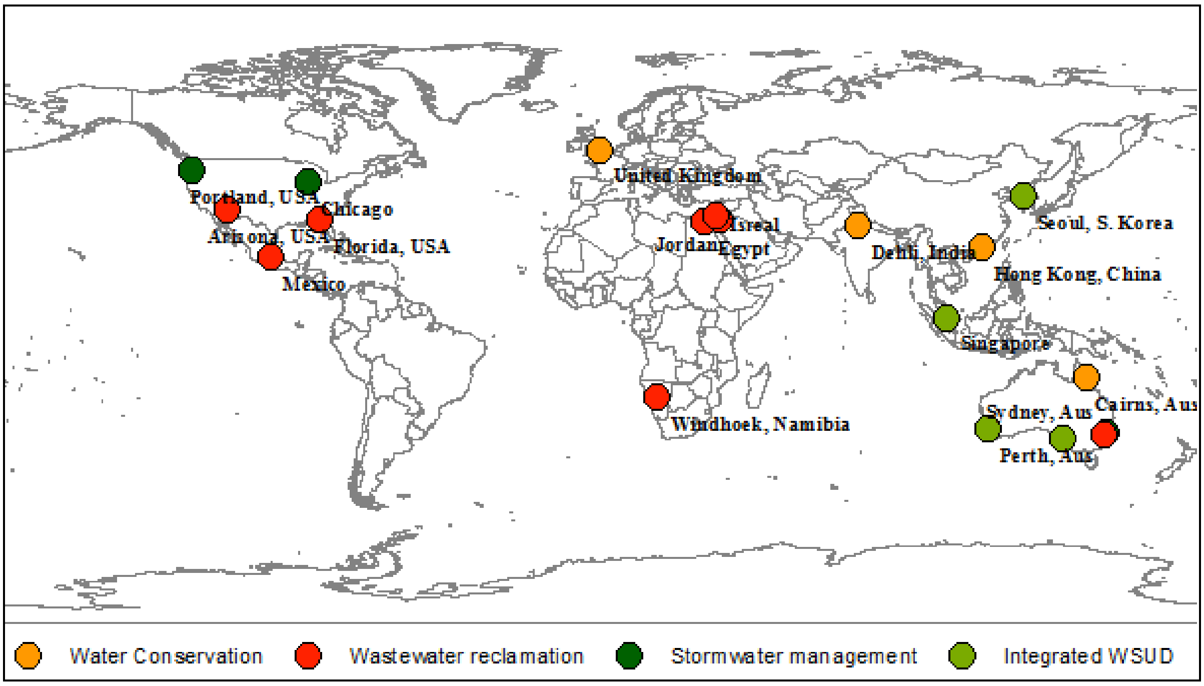
- Continue to work towards achieving 100% access to safe drinking water and sanitation and making these services affordable for all.
- Actively seek to ensure that water is an equal driver for the planning of sustainable city creation and redevelopment by collaborating with planners and other sectors (e.g. transport energy).
- Focus on designing toward resource neutrality and zero emissions technologies where energy-water relationships are optimized.
- Promote solutions that link cities beneficially with the water needs of the community, energy, agriculture, industry and the environment.
- Actively seek to develop management and technical systems that are flexible and forward looking – robust and adaptable to new and changing requirements.
- Demonstrate and measure the contribution of the water sector to city liveability, including aesthetics, public health, environmental values and quality of life.
- Undertake meaningful communication and education activities that support achieving sustainable and liveable cities and communities, and build the skills to measure and understand community expectations and values.
- Promote improved governance in terms of regulations, financing and institutional arrangements that maximize opportunities and remove impediments and barriers.

The integrative practice of urban planning and design entrenched in the fundamental principles of WSCs reflects the trans-disciplinary approaches advocated for the creation of multi-objective, liveable urban areas such as are envisaged in the CoF programme (Ward *et al*., 2012). The authors argue therefore that WSUD, through its aspiration of making water central to the design and functioning of cities, could provide the over-arching design philosophy and framework for the development of these areas. Two IWA conferences on CoF were held during 2011 (in Stockholm, Sweden and Xi'an, China) focusing on water security for the world's cities, and how the cities could be redesigned – particularly in lower and middle-income countries – so as to minimise the use of scarce natural resources whilst improving access to water services. The 2013 IWA CoF conference held in Istanbul, Turkey served to highlight demonstration cases on WSUD drawn from communities around the world showing how they had responded to the challenges associated with the planning, design and operation of future water systems. The intention of the IWA CoF Programme is to establish communities of practice by way of Cities of the Future (and consequently WSUD) ‘chapters’ in countries around the world which can act as reference centres for the collaborative efforts required to foster adequate responses to future challenges with respect to water security.

2.2 International best practice in WSUD

Increasingly cities around the world are beginning to implement alternative water management approaches. As part of this study, a review of selected international case studies (locations shown in Figure 2.1) was undertaken to evaluate what lessons learnt internationally might be applied within the South African context (Wu, 2012). A summary of this report is provided in the paragraphs that follow, and the full case study review is available at www.wsud.co.za.

The most pertinent case studies to this research are those that have adopted an integrated WSUD approach; i.e. selected examples in Australia and Singapore (as shown by the light green dots in Figure 2.1) – specific details on these cities have thus also been provided in Appendix A of this report.



World borders sourced from: http://thematicmapping.org/downloads/world_borders.php
World cities data sourced from: http://www.arcgis.com/home/item.html?id=dfab3b294ab24961899b2a98e9e8cd3d

Figure 2.1: International WSUD case studies reviewed (Wu, 2012)

Whilst it is acknowledged that the reviewed case studies do not present an exhaustive coverage of WSUD type approaches, it is interesting to note their wide distribution. This indicates a global trend towards improving the management of water, and the adoption of alternative approaches – such as WSUD – that better manage water as a scarce resource.

Numerous examples of cities incorporating specific aspects of WSUD were found. These case studies typically consider one or two aspects of the urban water cycle. Wastewater reclamation is often integrated with local water supply and water conservation, for example in Namibia and the sewer mining projects in Australia. Stormwater management using Sustainable Drainage Systems (SuDS) is another WSUD component that is increasingly being implemented. SuDS – sometimes under the guise of a number of local names such as 'Best Management Practices (BMPs), Low Impact Development (LID) or Low Impact Urban Design and Development (LIUDD) – have been widely accepted as the best approach to stormwater management for the future. In numerous case studies, stormwater is either incorporated into aquifer recharge schemes, or is used through harvesting to directly augment water supplies. There are not many examples, however, of cities integrating all three of the urban water cycle components, i.e. water supply, sanitation and drainage. Currently, Australia is one of the main advocates of WSUD and has implemented several projects that aim to integrate the management of the whole water cycle. Similarly, Singapore's integrated water management model is a good example for other urban areas and clearly shows that it is attempting to achieve water sensitivity.

Experience is showing that WSUD can provide environmental, social, and economic benefits. A common benefit amongst all case studies is the savings in potable water, and depending on the WSUD measures implemented, water savings can be extremely high. A significant benefit of this is the resilience that is developed for these cities. Environmental benefits such as reducing the artificially-increased volumes of stormwater runoff as a result of urban development and the protection of groundwater resources can be achieved with stormwater management and aquifer recharge schemes. Social benefits are also possible; for example, stormwater management using SuDS in the USA has been shown to improve urban aesthetics. Conversely, in some of the case studies it was found that social issues also have the potential to limit the adoption of WSUD. This was mainly attributed to a lack of knowledge of the potential benefits of WSUD, and health and safety concerns. This is especially common when 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 WSUD initiatives. It is evident from the international case studies and supporting literature that the main challenges of implementing WSUD are not so much technological, but rather social and institutional.

2.3 Water sensitive settlements in a developing country context – 'transforming our cities'

Water Sensitive Urban Design (WSUD) is a multi-disciplined approach to urban water management that aims to holistically consider the environmental, social and economic consequences of water management infrastructure (Wong & Eadie, 2000). With this in mind, it is suggested that a Water Sensitive Settlement (WSS) is one where the management of the urban water cycle is undertaken in a 'water sensitive' manner (using the philosophy of WSUD), with the overall objective being ecologically sustainable development (ESD) – see Figure 2.2. By considering all aspects of the water cycle and their interaction with urban design, WSUD aims to be the medium through which sustainable development can be achieved. It should be noted however, that in order to achieve ESD it is critical that WSUD is set in an over-arching planning process which encompasses the desired ESD objectives upfront. In other words, urban planning should not only take place as part of the urban design process as shown in Figure 2.2, but should be integrated from the outset. This will be discussed in detail in Section 4.1.3.

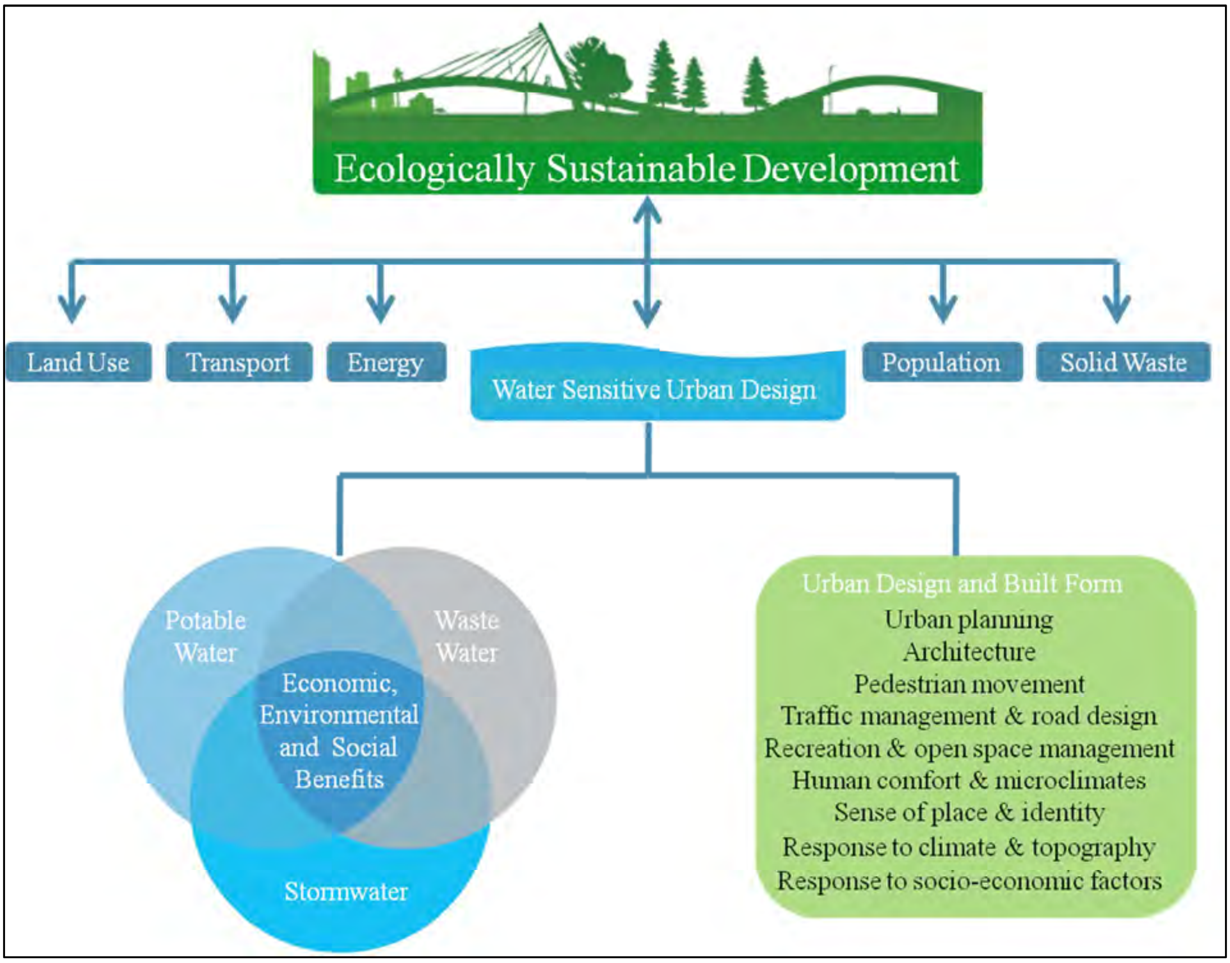


Figure 2.2: Interactions between WSUD, the built environment, and the urban water cycle (Hoban & Wong, 2006)

In Australia, a WSC is conceived as being the result of developing a town or city in such a way that it integrates "*the normative values of environmental repair and protection, supply security, flood control, public health, amenity, liveability and economic sustainability, amongst others. Communities would be driven by the normative values of protecting intergenerational equity with regards to natural resources and ecological integrity, as well as by concern that communities and environments are resilient to climate change*" (Brown *et al*., 2009). Society is reliant on a wide range of infrastructure of which urban water infrastructure is only one – albeit a very important element. The vision for WSSs is one where the urban water cycle is managed for the benefit of all whilst simultaneously protecting the environment. This is also increasingly being referred to as the provision of 'blue-green infrastructure', or the creation of 'blue-green cities' – aimed at recreating a natural water cycle while contributing to the amenity and liveability of urban environments (Novotny *et al*., 2010).

The recently-completed 'Sustainable Water management Improves Tomorrow's Cities Health' (SWITCH) project in the European Union's 6th Framework (FP6) is an example of a "*short-term, global experiment in the sociotechnical transition…of urban water planning and operational practices*" (Butterworth *et al*., 2011). Founded on a systems approach to urban water management, it made use of action-oriented, demand-led research in twelve cities in both developed and developing countries to show how an interdisciplinary and integrated approach might accelerate change towards a more sustainable future (Howe & Van der Steen, 2008). Key outcomes for the SWITCH project included encouraging city governments to consider alternatives to conventional ways of managing water in an integrated manner, thus facilitating the transformation towards water sensitivity. It should be noted that SWITCH was a truly global research effort – the consortium comprised 33 collaborating institutions with significant funding (> €23 million) – that enabled the sharing of knowledge across a range of different geographic, climatic and socio-cultural settings. On the other hand, while it undoubtedly had some major successes, the ending of the project also brought an end to the high levels of support (financial and capacity) which has impacted on subsequent progress. It is also important to recognise that the majority of the demonstration projects were site-scale initiatives, many of which with conditions somewhat different to those typically encountered, for example in the informal settlements in RSA.

In the RSA context, WSUD has the potential to: mitigate the negative effects of water scarcity; manage and reverse water pollution; develop social equity; develop intergenerational equity; increase sustainability; and develop resilience to natural disasters and climate change within water systems. In particular, it has the potential to transform the extremely divided settlements that are so typical of RSA into ones where water can be used to connect disparate communities and bring about significant change. That water needs to be a priority is widely acknowledged; for example the recently-published National Climate Change Response White paper (RSA, 2011a) encourages the development and use of WSUD principles to capture water in the urban landscape and to minimise pollution, erosion and disturbance. It also notes that "*urban infrastructure planning must account for water supply constraints and impacts of extreme weather related events*" (RSA, 2011a).

It is clear that what is required is a fresh approach to the planning, design and implementation of systems that would improve the use of water with regard to its consumption and quality. WSUD offers a means of doing this in order to facilitate the transition to WSSs. Implementing WSUD in RSA however, requires consideration of a number of issues, such as:

i) **Institutional structures:** The fragmented 'silo-management' of different aspects of the urban water cycle occurs, in part, because of the allocation of different responsibilities to different municipal departments. For example, stormwater management is often undertaken by the roads department – with stormwater seemingly being seen as hazardous water that needs to be disposed of as rapidly as possible. Water supply is often separated from sewage collection, treatment and disposal, etc. This has resulted in poor communication and integration of services.

ii) **Champions:** Identifying and supporting champions will likely be essential to introducing and embedding a WSUD approach in RSA. As has been found in a number of international cases (e.g. Taylor, 2010), progress will be more rapid where there is a 'champion' in a position of authority in any given town or city. Unfortunately the institutional silos described above have precluded these initiatives from being followed by water and sanitation departments in the larger municipalities, and capacity / skills shortages hamper these efforts at the smaller local authorities around the country.

iii) **Equity:** Includes dignity, ownership and respect. RSA already faces challenges in the delivery of services to the previously disadvantaged. Attempting to do this in a 'green' or water sensitive manner adds another layer of complexity. It will be difficult for the government to implement 'green' projects when basic services do not exist, unless these are accomplished simultaneously.

iv) **Health aspects:** The planning for, and implementation of, the WSUD approach in a developing nation such as RSA needs to take into account the potential health risks, particularly in respect of the creation of different pathways (mainly waterborne) for spreading disease.

v) **Adaptability & uncertainty:** RSA has technical capacity and skills constraints at local and national government level, and it is crucial that any developments do not 'lock' the country into overly complex technologies in the long term. Furthermore there is a great deal of uncertainty about the future including: the impacts of climate change, politics, demographics and resulting water demand patterns that result in policy makers being risk-averse.

vi) **Mitigation:** RSA needs to manage its environmental impacts. According to the World Bank (2011), RSA has the 42nd highest (out of 224 countries) output of CO_2 per capita. This is a powerful argument for a WSUD approach if this means keeping energy usage in check, e.g. by preventing the general move to the desalination of seawater.

vii) **Ecosystem Goods & Services (EGS)**: The SWITCH project (Butterworth *et al.*, 2011) proposed the economic valuation of ecosystem services as a means of motivating for the adoption of the WSUD approach. Ecosystem services are defined as the benefits people derive from ecosystems – these include provisioning services such as: food, wood and other raw materials; plants and animals that provide regulating services such as pollination of crops, prevention of soil erosion and water purification; and an array of cultural services, like recreation and a sense of place (Millenium Ecosystem Assessment, 2005). While this approach may be useful in developed countries, it is unlikely to have as much impact in RSA. Given the widespread poverty and inequality in the country, politicians are likely to consider EGS as an unaffordable luxury and may well question the reliability, maintenance requirements, appropriateness, and ability to deliver services quickly in a WSUD approach. It is thus necessary to consider how the benefits of transitioning towards WSSs could be presented to different stakeholders in RSA. Table 2.1 indicates the likely areas of interest / opportunities for the various target audiences.

Table 2.1: Likely interest areas for different stakeholders

Stakeholder	Area of interest / Opportunities
Politicians	Provision of basic services; job creation
City officials	Costs and ease of maintenance
Private developers	Increased profit/ public image
Community interest groups	Job creation; public health and safety
Environmental interest groups	Protection of the environment
Private individuals	Additional costs/benefits per household

In short, a ‘water sensitive’ perspective in the South African context demands a clear vision of the future, long-term planning, and empirically-grounded and evidence-based strategies. The adoption of WSUD to effect the development of WSSs requires a proactive and holistic approach that is able to comprehend the consequences of such a transition and thereby to help overcome socio-economic barriers whilst simultaneously producing sustainable and equitable economic growth. It also requires protection and conservation of scarce natural resources in a manner that ensures that human and ecological well-being (including public health and overall quality of life) is enhanced.

3. Developing the framework

The management of water occurs within a highly complex and multi-constrained social-ecological-political-economic context. Moreover, it cannot be undertaken in isolation from the management of other natural resources. To achieve adequate water management necessitates an integrated, trans-disciplinary and multi-stakeholder approach (Mollinga, 2008) which, in this instance, means having to share and translate data and information across disciplines (e.g. engineering, social, health and environmental sciences) and societal sectors, and thus producing a better understanding of the whole.

Water management in South Africa includes tackling 'wicked' problems – i.e. those that have "…multiple and conflicting criteria for defining solutions, solutions that create problems for others, and no rules for determining when problems can be said to be solved" (Rittel & Webber, 1973) – with respect to the delivery of services, particularly to those living in informal areas. Attempting to achieve urban water management in a 'green' or water sensitive manner adds another layer of complexity (Fisher-Jeffes *et al.*, 2012). Capacity, skills and resource shortages make this particularly challenging. To address these problems in a way that is water sensitive to the diverse human settlements that comprise most of South Africa requires a clear recognition of how the various stakeholders might work collaboratively to address the range of water security concerns that the country faces. It was therefore deemed necessary to get input from as many stakeholders as possible. A research team comprising academics and students from several universities, as well as officials working with four of the major metropolitan municipalities in RSA, was assembled. Disciplines included, inter alia, civil engineers, social anthropologists, environmental scientists, urban planners, political scientists, landscape architects, urban ecologists and hydro-geologists. Figure 3.1 indicates the range of skills and activities that could potentially be involved in the development of WSSs, and also highlights the four main cross-cutting themes that were identified as useful for the promotion of WSSs.

Learning Alliances (LAs) are one way of achieving the required trans-disciplinarity for WSUD. LAs are "*platforms that bring together stakeholders from a range of institutions...to think, act and learn together, using action research to test ideas*" (Butterworth *et al*., 2011). They allow researchers and multiple local stakeholders to work together to create shared visions, analyse options and develop new strategies for the management of urban water systems. LAs, as applied in the SWITCH project were "*based on the premise that when tackling a complex situation or 'wicked problem', a group of relevant people working interactively are more likely to come up with better options than a clever individual operating in a command and control situation*" (Butterworth *et al*., 2008). The purpose of a LA is thus to do things differently in order to have more impact on policy and practice – this is achieved through the skilled facilitation of a locally-derived and managed action approach (Verhagen *et al*., 2008).

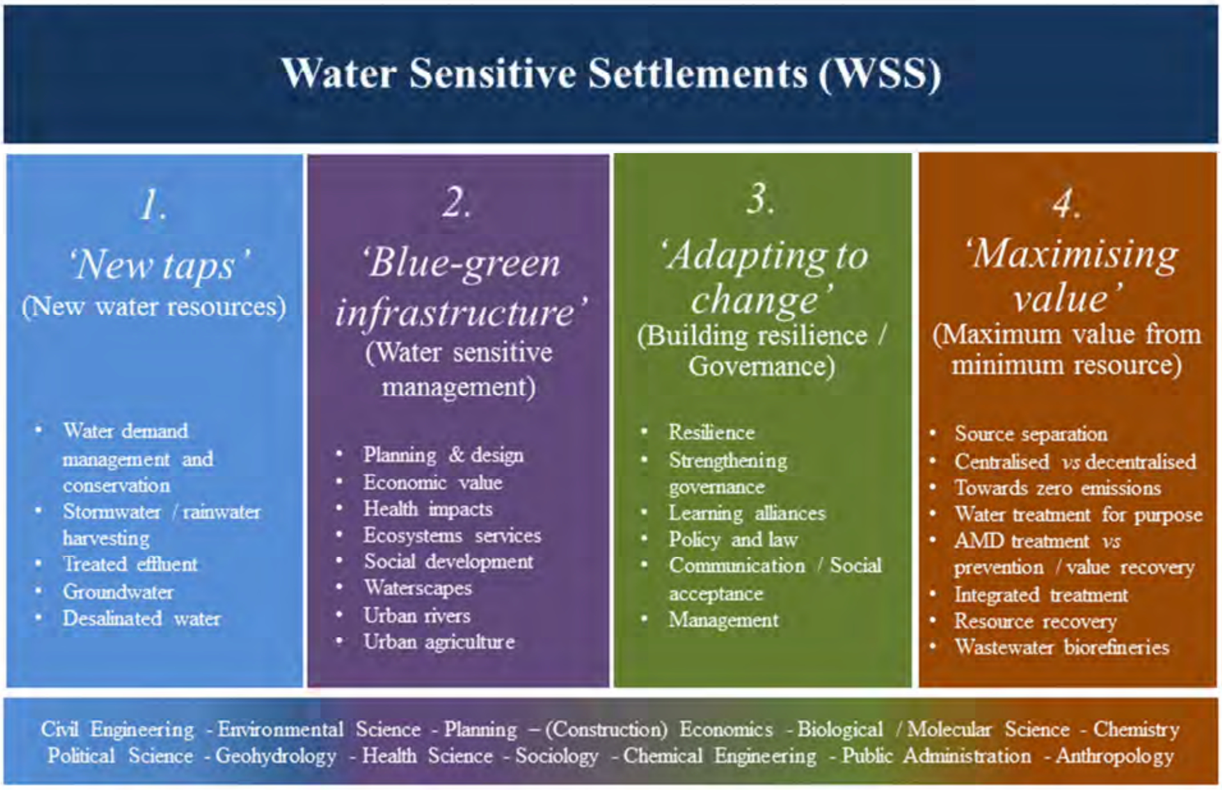


Figure 3.1: Trans-disciplinarity in WSUD leading to WSS

3.1 Research focus areas

The first task associated with the research involved a literature review (undertaken between July and December 2011) which explored the development and progression of the WSUD philosophy, WSUD technologies and available tools to assist in implementing WSUD. At the same time, a series of workshops were held with officials from the Stormwater, Water and Sanitation departments at the metropolitan municipalities of Cape Town, eThekwini, Johannesburg and Tshwane. Together these municipalities represent three different climatic zones, *viz*. coastal winter-rainfall, coastal summer rainfall, and inland highlands summer rainfall; an estimated 13 million people, i.e. some 26% of South Africa's population of approximately 50 million; and about half of its urban population (SACN, 2011). The workshops were used to introduce the researchers to key municipal officials as well as to identify potential opportunities and threats to the implementation of alternative approaches to urban water management in the respective municipalities. A workshop was also held at Drakenstein, a smaller local authority near Cape Town – to account for differences in opportunities that may be experienced by Category B local authorities. The workshop series concluded with a meeting in Cape Town where the outcomes of the various workshops countrywide were analysed, the research boundaries and objectives determined, and a plan for taking the project forward was developed.

One of the key findings of these workshops was that the concept of ‘water sensitive’, and the challenges and opportunities for ‘water sensitivity’ are context specific, and hence the tools and designs developed for/in RSA and other developing countries will likely vary from those implemented in developed countries. For example, the most water sensitive stormwater intervention downstream of a poorly serviced informal settlement could well be the construction of a low-flow diversion to the municipal wastewater treatment works in order to manage pollution – in direct contradiction to current regulations that stipulate the strict separation of stormwater and wastewater (e.g. CoCT, 2006a). Selecting water sensitive technologies could thus mean choosing the most appropriate / ‘fit for purpose’ technology that optimally manages water in a specific context. Existing WSUD guidelines from countries such as Australia have not been developed with the complexities of developing nations in mind; and as a consequence there is a need for relevant guidelines for the realisation of WSUD concepts in RSA and other developing countries. The need for on-going research to develop these guidelines is critical and, over time, local experience – in addition to theory – will start to inform the development of more appropriate tools and guidelines. In this regard, the development of guidelines needs to be an iterative process; as more technologies are trialled and evaluated the guidelines can be improved.

The outcomes of the municipal workshops were presented as a peer-reviewed paper at the 7th International Conference on Water Sensitive Urban Design in Melbourne in February 2012. Three members of the research team also attended the conference and associated workshops as a means of better understanding the development of WSUD principles in Australia. The paper highlighted an urgent need for capacity building in RSA – initially amongst municipal officials in particular, but thereafter amongst policy makers, consultants and communities (Fisher-Jeffes *et al.*, 2012). It was noted that simply publishing guidelines will not ensure the successful uptake of WSUD; there will need to be an intentional effort to engage with policy makers and/or individuals who can leverage their positions to ensure that the concepts of WSUD and WSSs are written into local and national policy – thereby resulting in more technologies being trialled in RSA. It became clear that progress would likely be defined by four sequential steps – which would be iterative:

i) Development of **tools** (manuals, guidelines, etc.).

ii) **Transfer** of knowledge to appropriate officials.

iii) Application of **tactics** for encouraging WSUD implementation (such as getting policy makers to write the information into relevant documents).

iv) Testing of water sensitive technologies and approaches through various **trials** (pilot studies, small scale developments, etc.).

These focus areas, summarised as the ‘4T’ concept of ‘tools, transfer, tactics and trials’ (Figure 3.2), were thus conceptualised as the first component of the framework for promoting the adoption of WSUD in RSA. As the order suggests, it is important to first develop tools, which can be transferred, and then to apply tactics and develop trials after which the cycle begins again with the improved tools that have come about as a consequence of lessons learnt.

Figure 3.2: The '4T' strategy to promote WSUD

3.2 'Learning Alliance' arrangements

Limited resources – both financially to support travel on a regular basis across RSA, and in terms of capacity / ability of individuals to become committed to the notion of a LA – posed a significant challenge for the research. For this reason, two separate groups of people made up the overarching or 'supra' LA – the first comprised researchers from the University of Cape Town (UCT), invited experts representing a range of disciplines, and officials from the City of Cape Town Municipality who attended meetings when possible. The second, much larger group which met far less frequently, was made up of the researchers from UCT, plus academics from the Universities of Stellenbosch and the Witwatersrand, as well as municipal officials from the cities of Cape Town, eThekwini, Johannesburg and Tshwane.

The development of the framework was made possible largely through the collective insights gleaned from regular meetings of the first group, which were then reviewed by the second group. All meetings were documented and the minutes made available to the entire 'supra' LA via the project website and by email. Members were encouraged to provide comments and input as necessary. These comments were then reviewed and, where appropriate, incorporated into the framework. This approach – whilst not ideal owing to the fact that the meetings were not run by an independent facilitator (due to budget constraints) – nonetheless ensured optimal use of the limited capacity and expertise in RSA.

4. A strategic framework for WSUD in South Africa

4.1 Terminology

The WSUD approach as proposed by Wong & Brown (2008) and Brown *et al*. (2009) is understood in Australia as "*an approach to urban planning and design that integrates land and water planning and management into urban design. WSUD is based on the premise that urban development and redevelopment must address the sustainability of water*" (Engineers Australia, 2006). There are a number of different terms and concepts embedded in this definition of WSUD. Throughout the framework development process for RSA, terminology was found to be crucially important. Extensive time was spent debating the different meanings at each workshop and meeting, with some members of the LA complaining that certain terms would exclude their professions, making it difficult for them to adopt WSUD and any related framework. Even when definitions from literature were discussed, many were found to be inappropriate or lacking for the RSA context – for example, the WSUD approach as originally envisaged does not take cognisance of the 'developmental' or 'equity' issues which are so prevalent in developing countries and especially pronounced in RSA as a result of the country's apartheid legacy. For example, it will be difficult for urban development and redevelopment to "*address the sustainability of water*" in a nation such as RSA where a substantial proportion of the population still do not have access to basic water supply or sanitation. Thus, while in principle 'leapfrogging' through developmental states is the ideal, there are social (equity) and practical issues that need to be considered. These issues are often built into, or associated with, the terminology and will be specific to each context. As a result it became necessary to define each term up front and describe what each means in the local context. The most significant terms and concepts are defined for urban water management in RSA in the sections that follow.

4.1.1 Water sensitivity

The concept of 'water sensitivity' referred to in Section 2.3 is relatively vague and does not fully recognise the challenges of working in a developing country context. In a society of extreme inequality such as RSA, social acceptance is the overriding consideration – without which progress will be severely hampered. The definition also fails to explain how individual values will be used to determine the 'community values' that are meant to govern urban design decisions. This is particularly problematic in RSA where the notion of 'community' (generally accepted as a group of people with a sense of collective purpose and a "*feeling… of belonging*" (McMillan & Chavis, 1986), is often notably absent, particularly in informal settlements.

In RSA there is also a strong emphasis on equity in access to water – both in terms of direct access to water for productive purposes as well as the benefits from resource use. The concept of developmental water management as described in the draft National Water Resource Strategy 2 (NWRS-2) has as its central premise that water plays a critical role in equitable, social and economic development in the country (DWA, 2012) – refer to section 5.2 for a more detailed discussion on the NWRS-2. For the purposes of this research, it was proposed that 'water sensitivity' be defined for RSA as the management of the country's urban water resources based on five principles selected from the National Water Act (RSA, 1998a), the NWRS-2, the RSA Constitution (RSA, 1996) and the Dublin Principles (UN, 1992) namely:

i) South Africa is a water-scarce (both physically and relating to access) country (e.g. Muller *et al*., 2009).

ii) Access to adequate potable water is a basic human right (i.e. water is a 'social good'), enshrined in the Constitution of RSA.

iii) Water has an economic value in all its competing uses and should also be recognised as 'natural capital' or an 'economic good' – including the recognition of ecosystem's provision of goods and services.

iv) Management of water should be based on a participatory approach involving users, planners and policy-makers at all levels.

v) Water is a finite and vulnerable resource, essential to sustaining all life and supporting development and the environment at large.

4.1.2 'City' *vs.* 'Settlement'

The term 'city' was used during medieval times to refer to a cathedral town, but originally it meant any settlement, regardless of size (OED, 2012). This can be misleading however, as it notionally implies a large permanent settlement. This has the potential, for example, to incorrectly imply that the WSUD framework would only apply to major cities such as Cape Town or eThekwini, excluding smaller urban centres or towns.

As was described in the Introduction to this report, the term 'city' has thus been replaced with 'settlement' in the Brown *et al*. (2009) framework for RSA purposes. This makes it clear that WSUD is appropriate for a wide range of settlement types ranging from category A (metropolitan areas) to category B (including secondary cities, large and small towns / villages, and settlements in rural areas) municipalities as defined in the Municipal Structures Act (RSA, 1998b).

4.1.3 'Urban design' *vs*. 'Urban planning'

The term 'urban design' as used in the term 'Water Sensitive Urban Design' was a significant point of discussion and distraction at each meeting or workshop, with recommendations that it needed to be changed or better defined as it appeared to exclude the discipline of urban planning, thereby preventing certain important stakeholders from taking ownership of the ideals of water sensitivity. Even the notion that 'design' includes 'planning' was unacceptable to most of the stakeholders. Whilst Table 4.1 highlights the fact that the terms are intrinsically linked, in the RSA context urban planners generally undertake planning (which is very often site-focused and does not consider the broader system), whilst engineers, architects, landscape architects and scientists undertake design.

Table 4.1: Urban design *vs*. Urban planning

Urban design	Urban planning
Urban design involves the arrangement and design of buildings, public spaces, transport systems, services, and amenities. Urban design is the process of giving form, shape, and character to groups of buildings, to whole neighbourhoods, and the city (Urban design, 2012).	*1. The branch of architecture dealing with the design and organization of urban space and activities* *2. Determining and drawing up plans for the future physical arrangement and condition of a community* (urban planning, n.d.)
Urban design is a well-recognised field associated with the planning and architectural design of urban environments, covering issues that have traditionally appeared outside of the water field but nevertheless interact or have implications to environmental effects on land and water (Wong & Ashley, 2006)	*Urban planning concerns itself with both the development of open land ('greenfield sites') and the revitalization of existing parts of the city, thereby involving goal setting, data collection and analysis, forecasting, design, strategic thinking, and public consultation* (Encylopedia Britanica, 2012)

If the objective of WSUD is to produce ecologically sustainable development (as highlighted previously in Figure 2.2) however, urban planning should be seen as the technical, iterative process which is used to guide and set the design for an appropriate urban form. In other words it reinforces the notion that the two terms need to be strongly linked in the WSUD approach.

In order to ensure that no profession would be excluded, and in the context of this research, the individual terms can be differentiated as follows:

- **Urban planning** is the process that considers the function and 'bigger picture'; i.e. the suburb, catchment, city, country and even continent, and whether / how factors and changes in each of these could or should direct development / redevelopment of an area; for example, if the National Development Plan (NDP) is aiming at 6% growth over the next 30 years (RSA, 2011b), what implications would this have on water resources, and how can these be resolved? Urban planning does not concern itself with the specific details of implementing a development.
- **Urban design** refers to a more local design (or form) of an area, and should fit in with existing urban plans.

4.1.4 Urban management

Aside from the design and planning aspects, another issue for consideration of the implementation of WSUD in RSA is urban management. This entails the operational and maintenance aspects, community awareness building and education, optimisation of the use of resources, and the identification of infrastructure needs emanating from the planning process.

Effective urban management is required for all urban infrastructure and not specifically for water infrastructure.

4.1.5 Water Sensitive Urban Design (WSUD)

The concept of WSUD has recently been included in a number of local- and national-level RSA policies; in many cases as a direct result of members of the LA motivating for it with the intention of using these policies as leverage for change within their (municipal) environments. The term WSUD is therefore already being used in RSA, although it is not well understood. Whilst the initial intention was to use the well-known and widely-accepted Australian term of WSUD in the development of a framework for the RSA context, as a result of extensive discussion with stakeholders from the relevant professions, the term was split into three components to be considered in an integrated manner, with the ultimate goal being the achievement of WSSs (Figure 4.1).

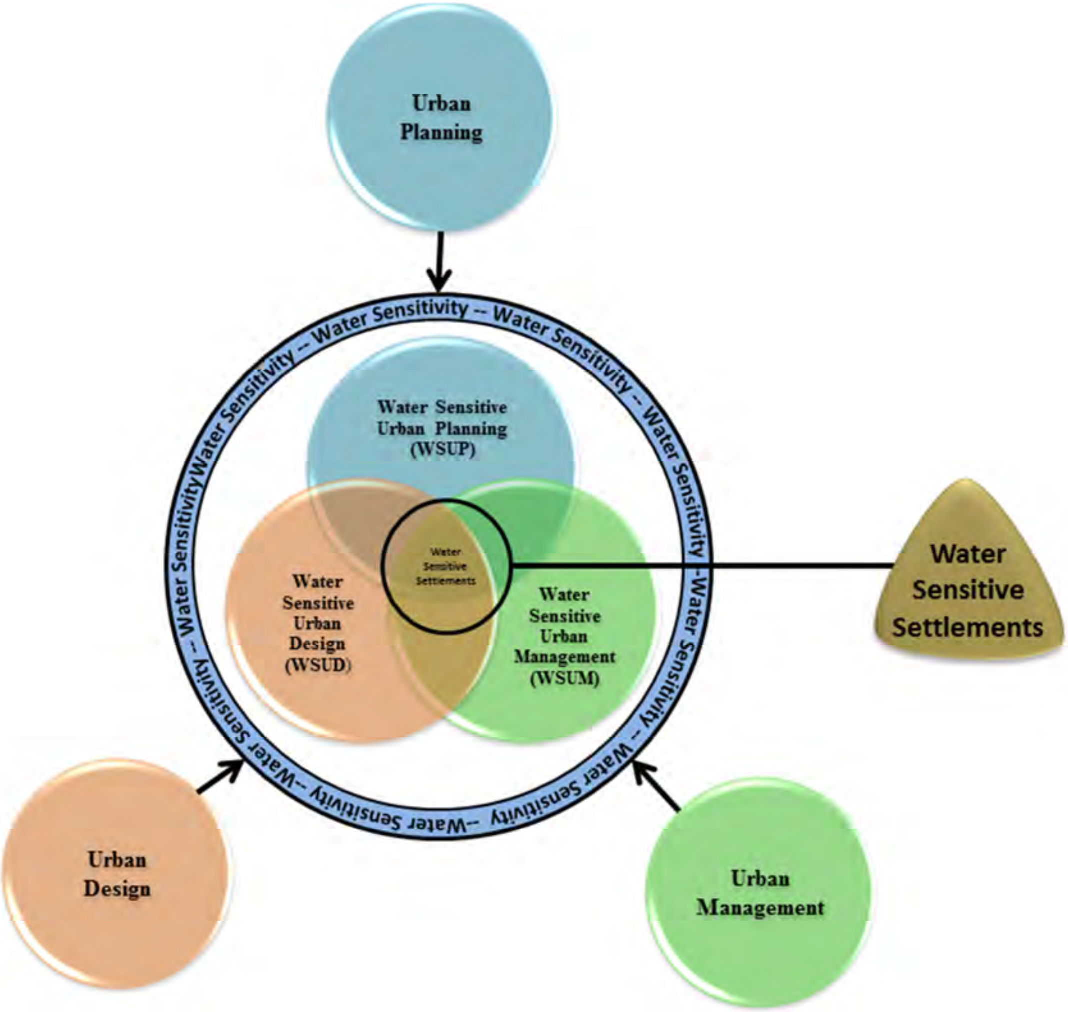


Figure 4.1: The integration of WSUD, WSUP and WSUM towards WSS

The three components are as follows:

i) **Water Sensitive Urban Design (WSUD**) – WSUD brings the concepts of ‘water sensitivity’ and ‘urban design’ together, ensuring that ‘urban design’ is undertaken in a ‘water sensitive’ manner.

ii) **Water Sensitive Urban Planning (WSUP) –** deals with urban planning and governance aspects. In the context of current water and environmental crises water planning needs to be undertaken at the highest level. The term WSUP brings together two components: ‘Water Sensitive’ and ‘Urban Planning’, ensuring that ‘Urban Planning’ is undertaken in a manner that considers and treats water sensitively.

iii) **Water Sensitive Urban Management (WSUM) –** deals with the post construction management of infrastructure. WSUM is the management of specific infrastructure supporting the three streams of the urban water cycle in a manner that is sensitive to the ecosystem and to the needs of affected individuals.

One of the major challenges to effective management of the urban water cycle in RSA is the current style of fragmented ‘silo-management’ of different aspects. While slightly different combinations of professionals will be involved in WSUD, WSUP, and WSUM it is vital that these terms do not create silos of their own. Furthermore, WSUD has to be managed according to planned interventions; i.e. by way of an over-arching planning process. Figure 4.1 shows how WSUD can be operationalized and institutionalised in RSA. It highlights the fact that only when the three concepts come together is it possible to have a WSS. Additionally, Figure 4.1 shows that neither WSUP nor WSUD nor WSUM is the ultimate goal; rather the goal is to develop a WSS through the combined adoption of all three approaches. This requires officials and stakeholders at all levels to work together. To facilitate this, the intention is to set up a number of local and more structured LAs.

4.1.6 Green Infrastructure

Whilst the term ‘Green Infrastructure’ (GI) is not directly linked to the Australian definition of WSUD, it is a term that is increasingly used worldwide. In the USA for example, GI is equated with best management practices (BMP’s) for water management (e.g. USEPA, 2013). In RSA, as a result of the energy crisis of 2007, the term was originally linked mainly with renewable energy production (Creamer, 2010), but has since been defined as “*infrastructure that is good for the environment and for sustainable development*” (DBSA, 2011). The term has two components:

i) **Green –** refers to a paradigm where the sustainability of the ecosphere is ensured. This is accomplished through design, planning and management aspects that mitigate the negative impacts that individuals and society in general have on the ecosphere.

ii) **Infrastructure –** refers to all physical, organisational, and social structures that support the existence of society.

GI brings the concept of 'green' to the planning, design and management of both hard and soft infrastructure. Figure 4.2 describes the different types of infrastructure as they are conventionally considered and managed at local authority level in RSA – i.e. in silos – whilst illustrating how GI connects with them. GI requires all infrastructure – hard (i.e. the physical structures) and soft (the institutional elements that support the infrastructure) – and their interconnections to be considered together through a 'green' framework which emphasises the health and sustainability of ecosystems. As illustrated in Figure 4.2, it is not possible to develop 'green' hard infrastructure without considering 'green' soft infrastructure.

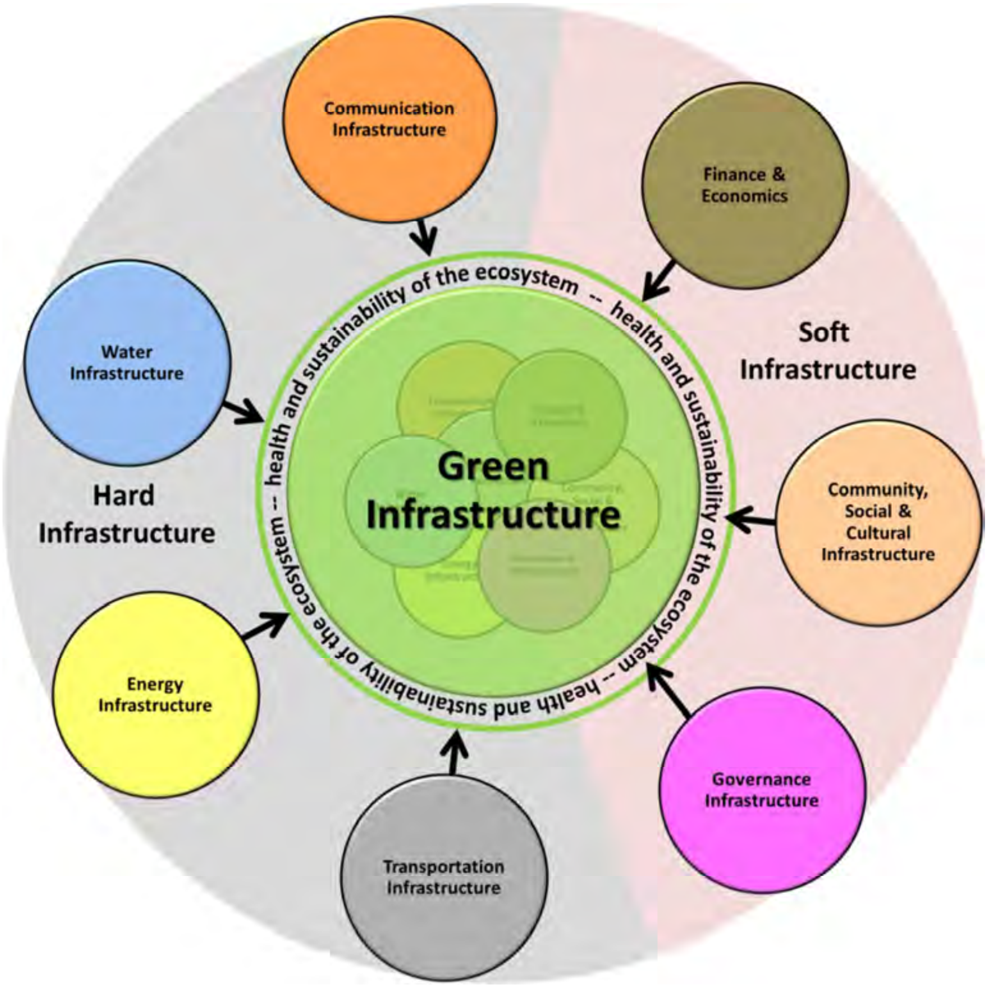


Figure 4.2: Green Infrastructure

GI can also refer to a way of linking green 'corridors' or spaces through urban and rural environments to build a green network to connect ecosystems and encourage biodiversity. Blue-green infrastructure takes the concept a step further with a focus on water. Essentially blue corridors, or a network of water bodies, are connected with green corridors so as to ensure the protection of natural systems and restoration of natural drainage channels, the mimicking of pre-development hydrology, reduction of impervious areas, surface storage and the use of water retentive plants (Novotny *et al*., 2010). The primary objectives of these SuDS-related components are water use / re-use, water treatment, detention and infiltration, conveyance and evapotranspiration. As with GI, it is postulated that barriers to the effective implementation of blue-green infrastructure can arise if planning processes and wider urban system design programmes are not fully integrated (*ibid*).

4.1.7 Sustainability & Sustainable Urban Water Management

The term sustainability, derived from the Latin *sustenere* (*sus* – up, *tenere* – hold), essentially means 'the capacity to endure'. In ecological terms, it relates to how biological systems remain diverse and productive; and in social (human) terms, it is the potential for long-term maintenance of well-being, depending on the responsible use of natural resources. According to Bell & Morse (2008), sustainability is essentially a combination of a "*call to action, a task in progress and a goal for the future*", and equates to a situation where the quality of a system remains the same or increases. Systems are described in terms of environmental, social, economic and institutional considerations, and sustainability implies the continuous and mutually compatible integration of these components over time. The transformation of cities to include sustainable urban water management concepts requires not only the integration of the components of IUWM and the various disciplines associated with the provision of water services, but also a paradigm shift in urban design so as to bring in aspects of 'sensitivity to water' and create landscapes that have "*intrinsic ecological functions related to the community and environment*" (Wong & Brown, 2008).

Systems thinking and integrated planning approaches are critical to the sustainability of any water services delivery / management program; this is especially relevant in a developing country such as South Africa where a context-specific interpretation of sustainability needs to take into account social and institutional issues such as poverty alleviation, strengthening democracy, skills levels, biodiversity conservation, etc. (Carden & Armitage, 2013). As Nleya (2008) puts it, "*Perhaps the biggest water and sanitation problem is how to achieve the triple objectives of efficiency, equity and sustainability*". In order for water services to be sustainable in this context, economic growth has to be targeted towards the equitable distribution of benefits (i.e. the needs of the 'poor') as well as being sensitive to the needs of the environment. The concept of sustainable urban water management (SUWM) in RSA is unlikely to be recognised by politicians unless economic benefits can be shown or there are clear links to development (e.g. through job creation, economy expansion, or opportunities for redress).

4.2 South Africa's framework for Water Sensitive Settlements

The transformation of towns and cities in order to effect the realisation of WSSs in RSA will require a significant shift in the manner in which urban water is currently managed. Historically, water systems were developed using a linear design approach; i.e. source, treat, transport, distribute, collect, treat and dispose. This technologically-driven approach was removed from the citizens it served. In order for WSSs to become embedded in RSA the proposed framework needed to address several important questions that arose during the different workshops and LA meetings:

- What are WSS's? What do we need to do to support a transition (understood here as a "*change in infrastructure and services in societal systems*" – see De Haan *et al.*, 2012) towards WSS's? How can this be achieved, especially with limited funding and capacity?
- What is the long term goal?
- Whilst the ideals of LAs and integration are accepted, how can the WSUD 'message' be conveyed so that all stakeholders are 'speaking the same language'?
- How can under-capacitated municipalities be expected to transition to WSSs? What new governance systems would be required to influence a step change in this regard?

In response to this, a framework with four components was developed as outlined below and described in the following sections:

i) Research component – describes how capacity can be built.

ii) Vision component – lays out the long term direction in which to move.

iii) Narrative component – to be agreed on by all stakeholders.

iv) Implementation component – a simple but adaptable approach that may be applied to identify how best to use resources in order to move towards the goal of a WSS.

4.2.1 Research component

As described in Section 3.1, there is a need for on-going research and capacity-building in the water sector in order to develop RSA-relevant guidelines for the realisation of WSUD. The '4T' concept of 'tools, transfer, tactics and trials' previously described was therefore conceptualised as a useful and flexible strategy in this regard, and became the first component of the proposed framework (Figure 3.2). Thus, applied to this research: the proposed framework and associated reports are the first 'tools'; the conference presentations, postgraduate courses and input into workshops comprise the 'transfer' aspects; collaboration and input into policy documents are 'tactics'; and these first three stages have begun to result in municipalities and private developers undertaking 'trials'.

4.2.2 Vision component

The well-recognised 'Brown framework' (Brown *et al.*, 2009) for visualising transitions within the urban water management sector (Figure 4.3) details the critical stages through which towns and cities progress as they aim to become more sustainable. Six urban water transition states and their associated socio-political drivers and service delivery functions are identified and used to underpin the development of urban water transitions policy and to benchmark a city's progress (either forwards or backwards) at a macro scale. As a result of being envisaged mostly for cities in the developed world, the 'Brown framework' does not take into account the impact on the urban water cycle of a number of factors unique to RSA and other developing countries. It has thus been adapted for this context as shown in Figure 4.4.

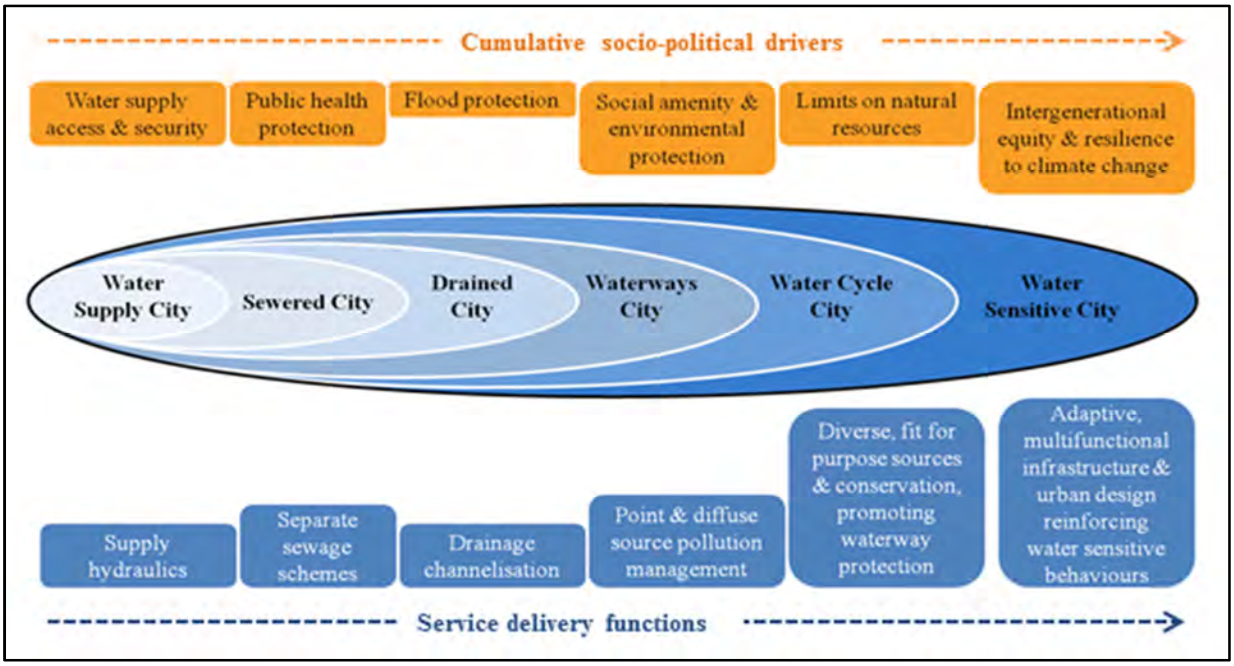


Figure 4.3: Urban water management transition states (Brown *et al*., 2009)

Brown *et al.* (2009) describe the transitions for formal settlements in detail; it is worth noting that most formally-developed areas in RSA cities would fit their description of 'drained cities'. If RSA wishes to transition towards WSSs in line with current international best practice however, the legacy of Apartheid – the policy prior to 1994 of 'separate development' for different ethnic groups – will need to be taken into account. This policy was "*an instrument of crude social engineering, causing great hardship and imposing an unnecessary burden on the economy*" (Turok, 1994). In essence the apartheid state refused to acknowledge "*Africans as permanent urban inhabitants ... investment in housing, infrastructure, education and other essential services in the townships was pared back from an already low level, in order to eliminate any such attractions the cities might offer to people from rural areas*" (*ibid*). This resulted in significant backlogs in infrastructure – which the current government is attempting to address. Typical of these backlogs are the large numbers of poorly-serviced informal settlements. Although the government has committed itself to upgrading these settlements, progress has been very slow and currently services are just as likely to be implemented as a response to civil unrest, pressure from Non-Governmental Organisations, or in response to natural disasters, as part of any long term plan. The situation is exacerbated by the 'silo management' within most municipalities in RSA.

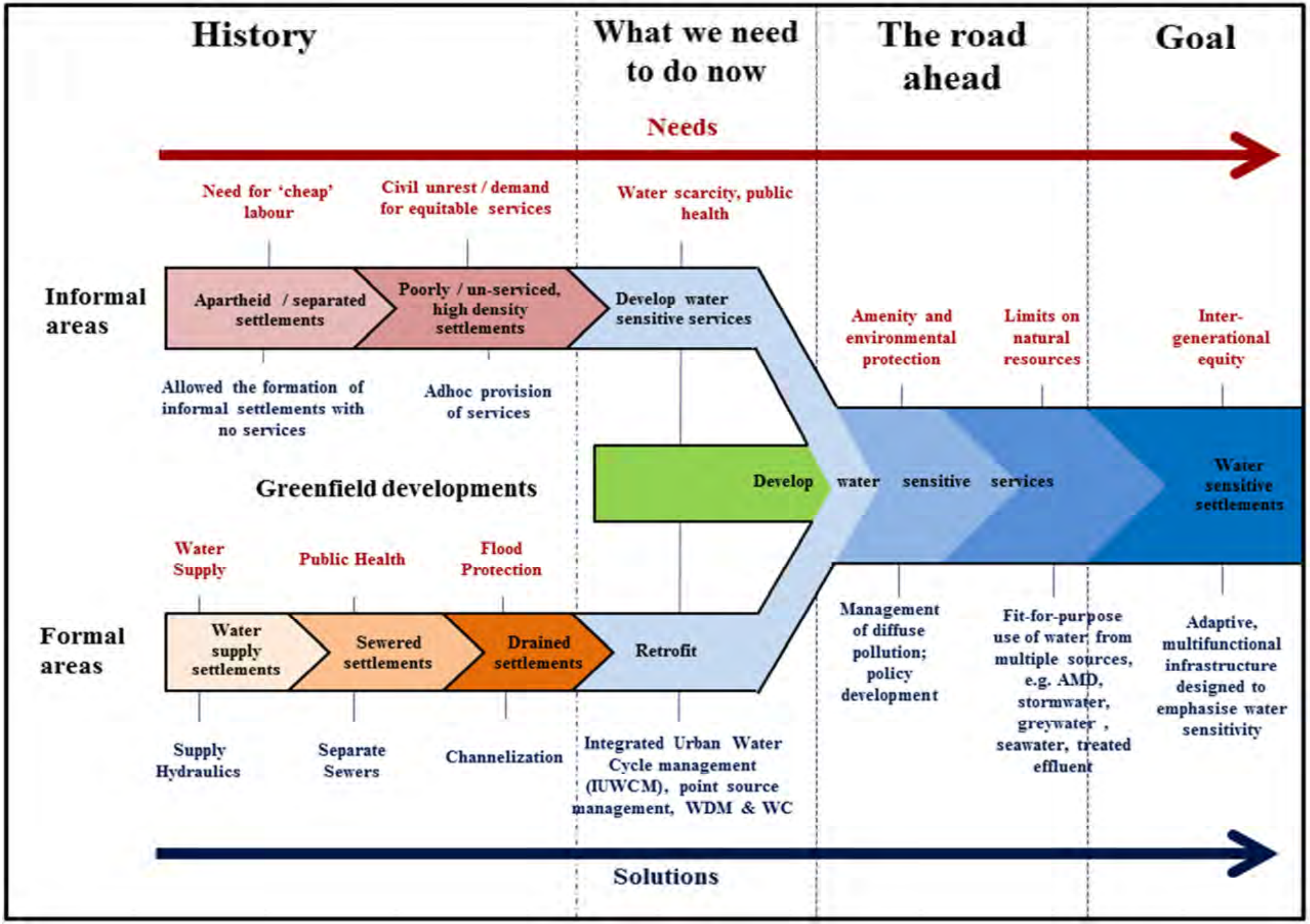


Figure 4.4: Framework for Water Sensitive Settlements in RSA, *"Two histories, one future"* (adapted from Brown *et al.*, 2009)

Any attempt to transition to WSSs in RSA will need to consider both the formally-developed areas (broadly equivalent to their counterparts in Australia, North America and Europe), as well as the informal settlements where high densities and limited infrastructure are common. Figure 4.4 provides a vision of how it may be possible to effect the transition of both formal and informal areas in RSA as follows:

i) **Formal (brownfield) areas**: Currently developed mostly as 'drained cities', these areas should attempt to transition towards WSSs through retrofitting and redeveloping brownfield sites in a water sensitive manner.

ii) **Informal areas**: once formal areas have begun to be retrofitted and the technologies tested on the mainly wealthy people there, informal areas (currently developed as 'water supply cities' with limited sanitation) should be redeveloped in as water sensitive a manner as possible. Any development of informal settlements should attempt to 'leapfrog' the stages through which formal areas develop, thus negating the need at a later stage to retrofit these areas. Using water sensitive technologies should also result in a range of secondary benefits for these communities. Care should however be taken to make certain that programmes are put in place to ensure adequate maintenance of the system/s.

iii) **Greenfield developments**: Greenfield developments should be done in as water sensitive manner as possible from the outset, particularly in the case of private developments where the municipality can use development planning approval processes to ensure that the concept of water sensitivity is incorporated.

Whilst it is acknowledged that there are several constraints to the (re)development and/or upgrading of informal areas in a water sensitive manner – for example, the National Housing Policy advocates basic service provision (water supply and sanitation) only, and budgets are allocated accordingly – it is important that this takes place simultaneously with the residents of formal areas being educated and encouraged to retrofit their systems to be more water sensitive. To transition either formal or informal areas alone would be not be possible in RSA; the burden, benefits and responsibility of and towards implementing WSUD has to be borne by all residents. Only then would it be possible to move forward equitably and continue to transition towards WSSs. The transitions diagram therefore emphasises the fact that enhancing water sensitivity in settlements has the potential to not only address issues of resource availability and environmental damage, but also to address related problems of social exclusion, equity and equality.

4.2.3 Narrative component

Narratives *"… simplify and offer a stable vision and interpretation of reality and are able to rally diverse people around particular story lines*" (Molle, 2008). This concept may be applied to the vision of a WSS where frameworks often fail to capture and express why a WSS should be adopted. The narrative 'tells the story' in order to draw people in; it expresses why a WSS is needed; how a WSS can be implemented; and what the outcome should be. The WSS narrative for RSA has been developed to tie together the other three components of the framework, so that at the very least all stakeholders should understand and engage with the idea of a WSS.

Why?

"…mitigating water scarcity, improving water quality, thereby protecting ecosystems, through the development of water sensitive urban areas (for all) that are sustainable, resilient and adaptable to change, while simultaneously being a place where people want to live…."

Result! **How?**

The terms that have been used as part of the narrative have been expanded and interpreted, specifically for the South African context, as shown in Table 4.2.

Table 4.2: Proposed definitions of WSUD terminology in South Africa

Term	Definition
'water scarcity'	An imbalance between availability and demand for water within an area (e.g. country, catchment, city), where demand threatens to overwhelm supply (see FAO, 2012).
'improving water quality'	Progressively working to better manage point source and diffuse pollution that is negatively impacting the natural ecosystem and or human health. This is accomplished through implementing best management practices throughout the urban water cycle.
'protecting ecosystems'	Ecosystems provide a range of goods and services. Protecting ecosystems will ensure the provision of these services in perpetuity. Protection of ecosystems includes managing environmental flows and water quality; biodiversity and corrective maintenance of systems impacted by urban areas.
'development'	The act of developing or redeveloping areas for residential, commercial or industrial use. The term development incorporates urban planning and design at all scales from catchment to household.
'water sensitive'	Management of water bearing in mind that: 1) RSA is a water-scarce country; 2) Access to water is a basic human right; 3) Water is 'economic good'; 4) Water management should be based on a participatory approach; and 5) Water is a finite and vulnerable resource.
'urban areas'	Any area primarily developed for residential, commercial or industrial purposes.
'for all'	The Water Sensitive Settlements approach is not for one sector of the community. WSUD should be implemented in all developments, across all racial and social classes, and in an appropriate and 'fit for purpose' manner.
'resilient and adaptable'	Ability to withstand natural disasters and adjust to changes in climate, population and social circumstances.
'a place where people want to live'	Conceptualised as a place where amenity forms part of the planning and design, and where people want to acquire property and live.

4.2.4 Implementation component

Various aspects are involved with the implementation of WSUD: policy development; institutional structures; community participation; construction of infrastructure; and operation and maintenance. However, the most important consideration in RSA is how to effect a transition to WSS in the context of limited resources – both human and financial. This requires careful consideration of what the vision of WSSs means in practice. For example, are all cities expected to simultaneously achieve the status of WSSs in the foreseeable future? It seems unreasonable to expect a municipality with limited funding and capacity to retrofit all of its systems. Using the analogy of Maslow's hierarchy of needs (Maslow, 1943), municipalities need to ensure that they are at least meeting the physical water needs of their residents whilst attempting to provide services which address the ideals of water sensitivity. This assertion is supported in RSA law and policy (e.g. the National Development Plan, see RSA, 2011b). Currently, for example, where there is a failure to provide adequately for the disposal of greywater and/or to provide adequate sanitation, stormwater systems will likely become the default disposal system / sewer – a management strategy that could potentially pose a public health threat. Ultimately all planning and expenditure should support the long-term realisation of the WSS goal and all development should incorporate the principles of water sensitivity. However, a municipality cannot focus on establishing ecosystem sustainability and intergenerational equity unless it can simultaneously provide adequate and safe water to all of its citizens. Conditions may however exist where this will not be possible (for example, the emergency provision of water services in an informal settlement after a fire); thus municipalities should target their initiatives with the underlying philosophy of: "*Do what you can with what you have*". This should be done while keeping in mind that, in achieving short-term goals, it is important not to jeopardise the long-term goal of a transition to a WSS; i.e. attempt to "*Do no harm*". Furthermore, individuals and developers in formal areas often have the capacity to develop in a water sensitive manner independently of the local authority. Municipalities should therefore ensure that they strengthen local legislation and regulations to encourage this – thus freeing up resources for other areas.

As more trials are undertaken in RSA the implementation component will be strengthened. It will be possible to learn the lessons about where, when and how to implement the vision of WSSs in informal areas. It will also be possible to develop what, if any, preconditions there are for implementing the vision of WSSs in different areas of South Africa. With this knowledge it will then be possible to prioritise investment to realise maximum benefits for the future.

5. Relating WSUD to development planning in South Africa

"*By 2030, most South Africans will have affordable access to services and quality environments. New developments will break away from old patterns and significant progress will be made in retrofitting existing settlements.*" (RSA, 2011b)

The adequate provision of water to RSA's citizens is one of the most significant challenges facing the country. If a water crisis is to be averted, existing systems will need to be managed effectively (Muller *et al.*, 2009), both in terms of quantity of resources as well as quality. This is particularly relevant in the rapidly-urbanising areas owing to the fact that they are hubs of economic growth, and could without proper management become major drivers for increased water demand. The various existing plans and strategies within the different sectors related to urban water thus need to be aligned to ensure that they are aimed towards a common goal of decoupling future economic growth from resource consumption. Two important documents have recently been released in RSA to guide management of the water sector in this regard – the National Development Plan (NDP), issued by the National Planning Commission (RSA, 2011b) with the aim of setting an overarching plan to eliminate poverty and reduce inequality, and the National Water Resource Strategy 2 (NWRS-2), published by the Department of Water Affairs (DWA, 2013). WSUD has the potential to act as the mechanism to address – and enhance – the objectives of the NDP and NWRS-2, and the framework for transitioning to Water Sensitive Settlements in RSA (hereafter referred to as the Framework) will show how this can be achieved. It is therefore suggested that the Framework could be adopted as a means of meeting the challenges facing the urban water management sector, and achieving the goals of the NDP and the NWRS-2 with respect to urban areas in RSA.

Government has committed to an "*integrated urban development approach*" (COGTA, 2013) to assist local authorities in managing the effects of rapid urbanisation as follows:

- A national integrated urban development policy framework is being advocated to improve planning and resource efficiencies so that better returns on investment can be achieved for every Rand spent on infrastructure in cities.
- Return on investment is envisaged as extending beyond economic returns to encompass social returns (i.e. improved quality of life, especially for the poor) and environmental returns (i.e. minimising damage and re-establishing ecosystem health) as well.
- The working assumption is that if South African towns and cities calibrate their infrastructure planning, investment and management, they can go a long way towards fostering more resilient and inclusive settlements, consistent with the over-arching national development goals.

- Infrastructure is understood as a socio-technical construct – i.e. it is more than just pipes. The success or failure of technologies will be strongly influenced by the institutional structures that support them and the people that use them.
- Environmental concerns do not take priority over social concerns – the focus is rather on achieving universal access to basic services in a manner that is resource-efficient so as to minimise environmental impact and improve affordability in the longer term.
- Resource-efficient infrastructure service approaches include those that:
    1. Minimise the use of raw materials and fossil fuels through efficiencies.
    2. Substitute non-renewables with renewable alternatives.
    3. Minimise the amount of waste and pollution dumped into the air, water and land by re-using waste streams as substitutes for raw materials.

5.1 Overview of the NDP

The Diagnostic Report of the National Planning Commission set out RSA's achievements and shortcomings since 1994 – and highlighted major developmental challenges in terms of inadequate infrastructure, poor quality education; high levels of unemployment; a resource-intensive economy, a failing public health system, poor quality public services and high levels of corruption (RSA, 2011c). The report acknowledged that the country should approach development needs differently – with growth and development, and reducing poverty and inequality as core elements: "*It requires shifting from a paradigm of entitlement to a development paradigm that promotes the development of capabilities, the creation of opportunities and the participation of all citizens*" (RSA, 2011c). In other words, the new approach requires that people are active champions of their own development, and that government should work to develop the capabilities required, and provide the opportunities for people to live the lives they desire.

The NDP's vision in respect of water services focuses on the alignment of the country's social and economic development with available water resources, and the protection of the natural environment through the prevention of excessive abstraction and pollution (RSA, 2011b). Amongst others, it states that: *"Before 2030, all South Africans will have affordable access to sufficient, safe water and hygienic sanitation to live healthy and dignified lives….The country's economic and social development will reflect an understanding of and an alignment with available water resources… All main urban centres will have a reliable supply of water to meet their needs…The natural water environment will be protected to prevent excessive abstraction and pollution"*. It is important to note that this should not mean that economic growth is necessarily coupled with water demand; rather that RSA needs to plan for, and find innovative ways of decoupling growth from the consumption of resources. Urban centres are not guaranteed unlimited access to water, rather access that is 'sufficient', 'reliable', and that will 'affordably meet the needs'. As will be discussed in the following section, it is intended that the reviewed NWRS-2 will be adopted as the guide to development in the water sector in RSA, in order to achieve the goals of the NDP.

5.2 Overview of the NWRS-2

"*South Africa, despite being a freshwater-scarce country, has sufficient water resources potential to meet its short to medium term requirements. The key challenge…is about mastering the art and science of unlocking potential resources, ensuring timeous accessibility, facilitating sector and business viability, ensuring sustainable water delivery and management as well as effective governance*" (DWA, 2012).

Much has changed in the RSA water sector in the last two decades since 1994, with substantial new policies and legislation providing a progressive water management framework. However, implementation of these new policies has been slow, particularly in relation to equity and redress in access to water, and water conservation and demand management. As required under the National Water Act (Act 36 of 1998), the 1st National Water Resource Strategy (NWRS-1) which was published in 2004 has recently been re-drafted as the 2nd National Water Resource Strategy (NWRS-2). Similar to the first edition which set out the 'blue print' for Integrated Water Resource Management (IWRM), the NWRS-2 provides an overview of the state of RSA's water resources, the challenges and opportunities facing the water sector; and sets out the strategic direction for water resources management in the country over the next 20 years, with a particular focus on priorities and objectives for the 5 year period 2013-2017 (DWA, 2012). It is the primary mechanism to manage water across all sectors towards achieving Government's development objectives. In particular it addresses concerns that RSA's socio-economic growth will potentially be restricted if water security, resource quality and associated water management issues are not resolved.

The vision underpinning the NWRS-2 is aligned with the vision of South Africa 2030 and is centred on the notion of 'Sustainable, equitable and secure water for a better life and environment'. Towards achieving this vision, the overall goal is of water being efficiently managed for equitable and sustainable growth and development (DWA, 2013). There are three main objectives, as follows:

i) Water supports development and elimination of poverty and inequality.

ii) Water contributes to the economy and job creation.

iii) Water is protected, used, developed, conserved, managed and controlled sustainably and equitably.

The vision reflects and builds upon the principles of equity, efficiency and environmental sustainability that underpin the National Water Policy and National Water Act, both of which are founded on the principles of IWRM.

5.2.1 Challenges

"*Although the regulatory framework and institutional arrangements have changed since the advent of democracy, one aspect remains constant: water scarcity – whether quantitative, qualitative or both – which originates as much from inefficient use and poor management as from real physical limits and the potential impacts of climate change*" (DWA, 2012). The NWRS-2 has attempted to address this issue through identifying five key management approaches, i.e. responding to specific socio-economic drivers; implementing a resource mix; ensuring access to water through effective implementation arrangements; sustainable service delivery through effective business management; and sustainable resource management through effective protection and conservation and proficient governance. There are several challenges with these approaches however, including a lack of accountability with respect to water and the fact that the role and status of water is not appreciated by many people. Inadequate funding and limited capacity are key problems in the management of water in RSA (DWA, 2012; Fisher-Jeffes *et al*., 2012).

5.2.2 Strategies & actions

Specific interventions have been highlighted for the facilitation of the NWRS-2 vision in the short- to medium-term and to avert a potential water crisis. Seven strategic themes have been identified to address water resource concerns and guide future water management and development in the country towards the achievement of Vision 2030 (DWA, 2013), as follows:

i) Water resources planning, development and infrastructure management.

ii) Water resource protection.

iii) Equitable water allocation.

iv) Water conservation and demand management.

v) Regulation.

vi) Managing water resources for climate change.

vii) International cooperation and trans-boundary management.

These core themes respond specifically to national priorities, and comprise the framework and context for a large number of strategic actions to be undertaken across the water and related sectors, specifically over the five year period 2013 to 2017. In order to facilitate implementation of the strategy, a water policy review process has recently been initiated within Government to provide legislation that is able to effectively ensure sustainable management of water resources. To this end, it has been suggested that there is a need to align the national Water Services Act (NWSA) with the National Water Act (NWA) and other national legislation that governs local government, particularly as they relate to development planning, regulation of water services provision (national and provincial intervention in local government), regulation of local government's reporting obligations in accordance with the provisions of national legislation, as well as the determination of norms and standards on issues of common interest. The Policy Review Process is therefore aimed at combining the NWA and the NWSA, thereby creating an integrated National Water Act (DWA, 2013).

5.3 Developmental water management

The NDP envisages "*a South Africa where everyone feels free yet bonded to others; where everyone embraces their full potential, a country where opportunity is determined not by birth, but by ability, education and hard work*" (RSA, 2011b). The NWRS-2's vision "*reflects and builds upon the principles of equity, efficiency and environmental sustainability that underpin the National Water Policy and National Water Act*" (DWA, 2012). Both the NWRS-2 and the NDP propose the adoption of 'developmental water management' (DWM), where water plays a critical role in equitable social and economic development and where Government has a critical role in ensuring that this takes place (DWA, 2012). Despite these documents having similar visions and acknowledging that RSA is a water stressed country, water resources are still not receiving the priority status and attention they deserve (DWA, 2012). The NWRS-2 and the Framework both note that by adopting a more holistic approach towards water availability, use and management, water resources can be defined in a much broader context. This will however require that the NWRS-2 is developed further and implemented with strong scientific support, good social dynamics analysis and innovative technological and systems solutions (Naidoo, 2013). An increased emphasis on the creation of water sensitive settlements is inevitable, and to this end, the Framework visualises the development of these WSSs.

5.3.1 Water Resources & Total Water Cycle Management

While water security is a major concern, there is no reason why RSA should experience a water crisis provided that existing systems are managed effectively (Muller *et al.*, 2009). DWA recognises that traditional water management approaches are insufficient to deal with the growing water demand and the increasingly complex water sector (DWA, 2012), and that proactive measures need to be taken to curtail water losses in particular if there is to be sufficient water to meet the country's needs into the future. A recent WRC study on the state of non-revenue water (NRW) in South Africa (McKenzie *et al.*, 2012) has indicated that current levels of NRW are of the order of 37% – a volume of around 1,580 million m^3 per annum, with an estimated financial value of R7.2 billion per year. The inclusion of water use efficiency, demand management, improved water governance, optimisation of existing water resources including groundwater, seawater, rainwater harvesting, re-use of water, resource protection and recharge, is therefore required if RSA is to have adequate water resource potential to meet its requirements (DWA, 2012). The NWRS-2 has taken a high level, traditional, approach to water resource management – in contrast to the above. The focus has been on ensuring adequate water for growth, with desalination implied as the next option to supply bulk water. The

NWRS-2 highlights the need to include alternative water sources in its bulk water calculations, but this seems to be little more than an unsupported statement designed to avert criticism for not considering alternatives to surface water. Further, the possible alternatives for supplying urban areas are not considered in any depth. For example: "*the DWA has therefore focused its planning efforts on the metropolitan areas where the needs are most urgent*" (DWA, 2012. p31), but there is no explicit strategic plan in the NWRS-2. In terms of water demand the NDP does not make provision for water for all desired uses; rather that there should be sufficient water to meet the needs of people at an affordable price, without negative impact on the environment. It is worth questioning therefore why the NWRS-2 has such a clear argument for desalination – which the NWRS-2 notes as expensive. At the same time there is limited focus on rainwater harvesting, and no consideration of potential of stormwater a resource. When considering stormwater, it is again clear that the DWA approach to IWRM fails to consider the total water cycle. As a result the significant impacts and consequences of urban runoff / stormwater and the potential to use strategies such as Sustainable Drainage Systems (SuDS) are not considered in the NWRS-2.

The NWRS-2 does not provide an adequately comprehensive approach to managing the Total Water Cycle. Whilst the Framework does not discuss the different alternative resources – based on the fact that it is simply a framework – the WSUD approach it motivates for encourages water management authorities to find 'fit for purpose' solutions that recognise the importance of the total water cycle and its impacts on other sectors. This is important as "*mastering the art and science of unlocking the potential resources*" (DWA, 2012, p iv.) and finding innovative solutions to ensuring water security, is unlikely to be a 'one size fits all' solution. Instead a 'fit for purpose' approach to WSSs is required. The NWRS-2 must include the concepts of WSUD and WSSs as a critical component of the strategy that deals with the planning design and development of cities.

5.3.2 Economics

The NWRS-2 highlights what is termed 'the total economic value' (TEV) of water and the need to cover total costs, but this is undermined by its failure to consider stormwater management, and highlight the total economic costs of alternative water sources within the strategy. Also, municipalities currently face significant funding shortfalls and many of these costs are externalised on to the environment; the NWRS-2 ignores both of these considerations. While the NWRS-2 details the economic theory relevant to the water sector, practically it fails to address the complexities of the urban environment. The Framework on the other hand recognises that part of achieving a WSS is an economic assessment of the provision of water services, and an evaluation of the secondary economic benefits (including ecosystems services) that could accrue from the implementation of an approach such as WSUD – see section 10.3.2 for more details in this regard.

5.3.3 Water-Energy-Food Nexus

The NWRS-2 briefly highlights the challenges relating to the Water-Food-Energy nexus; i.e. balancing the need to ensure water, food and energy security – which are all interlinked – with the need for social development. It mentions the possibility of importing food, resulting in a reduced need for irrigation (DWA, 2012), but this could decrease the country's food security. The generation of energy is water intensive. Therefore the use of energy intensive methods – such as desalination – to produce water is a counterproductive approach in a water stressed country. Furthermore, RSA already faces an energy crisis, so using energy intensive methods to generate potable water will exacerbate the energy crisis and decrease water security. It is therefore important that the 'fit for purpose' approach to water management that is central to WSS and WSUD be adopted – whilst still acknowledging the potential health risks related to the handling of possibly contaminated water.

WSUD aims to take advantage of ecosystem goods and services by 'greening' cities. An additional advantage of 'greening' is its impact on the heat island effect (Coutts *et al*., 2012), resulting in a reduction in energy consumption for cooling. In this case the adoption of the WSS vision would speak directly to the NWRS-2 call for integrated planning.

5.3.4 Climate change / resilience

Whilst the NWRS-2 identified the management of water resources for climate change as one of the seven strategic themes to be addressed (see section 5.2.2), very little attention was paid to how this could be achieved. A WSUD approach encompassing integrated planning at a macro-level (i.e. not just development control and spatial planning aspects) will be required within local governments in order that the risks associated with climate change impacts can be better understood and the necessary institutional responses can be put forward. The need for this level of planning was further highlighted in the 2011 State of the Cities Report (SACN, 2011), which focused on the resilience of cities in RSA, and in particular on their capacity to withstand and recover from external shocks, and adapt to changing circumstances. It noted that municipal authorities should go beyond the routine delivery of basic services to ensure urban resilience by, *inter alia*, reshaping and reconfiguring cities by way of strategic planning and investment to address future uncertainties like resource shortages, flood risks and climate change impacts.

5.3.5 Capacity building

The NDP, NWRS-2 and Framework all agree that there is a need to develop capacity if RSA is to implement any of these strategies. The NWRS-2 further identifies that the successful implementation of the strategy will depend on, *inter alia*, gathering adequate and reliable information; adhering to adopted policies and procedures; and the deployment of appropriately skilled people. The Framework, with its four components, suggests that there is a need to develop the tools, transfer the knowledge, and undertake trials to test new technologies and approaches to support WSUD. None of the documents provide guidance as to how or who will be responsible for co-ordinating these activities. The role of a regulator, or research and educational co-ordinator may be necessary.

6. Institutional considerations

6.1 Regulatory frameworks with particular reference to stormwater

The Constitution of the Republic of South Africa, Schedule 4 – Part B determines that the provision of stormwater services in urban areas is the responsibility of the local municipality (RSA, 1996). In many municipalities across the country, the management of stormwater has been separated from that of water and sanitation, with the former often being assigned to roads departments. This has resulted in stormwater being treated as 'hazardous water' that needs to be disposed of as rapidly as possible – in order to prevent damage to road structures. However, this paradigm fails to recognise a broad range of regulations and has resulted in the fragmented 'silo-management' of the different aspects of the urban water cycle. In order to optimise the benefits of the provision of water services (i.e. gain ecosystem goods and services, develop public use spaces, etc.) it is crucial that the urban water cycle be managed as a whole and not fragmented.

The Constitution, Clause 24b (RSA, 1996) and the National Environmental Management Act, NEMA (RSA, 1998c) guarantee citizens the right to an environment that is not harmful to their health or wellbeing. NEMA furthermore places a responsibility on developers to prevent practices that have harmful effects on the environment (Buys & Aldous, 2009). This point of view is strengthened by the National Water Act (NWA), Part 4 Section 19.1 (RSA, 1998a) that places the responsibility of controlling water pollution on the land owner. The regulatory framework in all three documents are at odds with the current approach to stormwater management which actively conveys often polluted stormwater to the nearest watercourse as quickly as possible, posing a potential public health risk and undermining citizens' rights to a healthy environment.

The National Water Services Act, NWSA (RSA, 1997a) places a duty on municipalities to develop water services development plans (WSDPs). Unfortunately, because stormwater is considered a part of the provision of roads, it is seldom comprehensively dealt with in municipal WSDPs. Often stormwater is only mentioned as a result of municipalities' problems relating to the ingress of stormwater into the sewage system, which overloads the wastewater treatment works and in some cases is a cause of water pollution. However NWSA (13 d) states that the WSDP should detail 'existing water services' and (13 h) requires the detailing of the water sources to be used and the quantity of water to be obtained from and discharged into each source as well as the maintenance and operation requirements – which should reasonably include stormwater. The NWA (Schedule 1 (1a)) does allow for the collection and use of runoff from roofs commonly considered to be 'rainwater harvesting'. Rainwater harvesting is also a stormwater management tool. Stormwater is a part of the urban water cycle which needs to be managed in an integrated manner in the WSDPs.

Currently the provision of stormwater management in RSA is largely funded from property rates, which means that stormwater departments have to compete with many other pressing needs when advocating for funding. Consequently stormwater departments throughout South Africa are chronically underfunded – with some estimated to be receiving as little as 10% of what is ideally required for maintenance (Fisher-Jeffes & Armitage, 2013). It has been suggested that South African municipalities should begin charging stormwater user fees to ensure there is adequate funding for stormwater management – a practice widely accepted internationally (*ibid*). In order for this to become a reality, national, provincial and local authorities will need to develop appropriate legislation.This legislation would need to allow flexibility in terms of water quality and quantity management due to the range of environmental factors that have to be considered.

At the time of writing, the City of Cape Town's Stormwater Management By-law (CoCT, 2005) and the associated Management of Urban Stormwater Impacts Policy (CoCT, 2009a) were RSA's most 'advanced' stormwater legislation, although by-laws relating to stormwater management have also recently been promulgated in Johannesburg and Tshwane. Whilst these are useful policies, further supporting legislation at all levels of government needs to be developed to: integrate the management of stormwater with the rest of the urban water cycle; provide for the funding of the provision of stormwater services; provide for the use of stormwater as a water resource; and provide for / encourage developers and municipalities to develop multifunctional stormwater services. See Table 10.5.1 in Section 10.6 for further details on existing stormwater legislation in RSA local authorities.

6.2 Legislation related to managing wastewater at a local level

The Water Services Act (108 of 1997) assigns the responsibility of managing water (and wastewater) provision to local government (RSA, 1997a). It is therefore at this level that by-laws have to be promulgated to manage the wastewater stream in urban areas. Table 6.1 highlights some of the policies and by-laws adopted by three of the major metros in South Africa; i.e. Cape Town, Johannesburg, and eThekwini.

Whilst these policies are useful in terms of managing the specific components of wastewater (and the potential re-use of treated wastewater) at local authority level, they do not necessarily account for integration with other urban water services. As with the existing stormwater legislation in RSA, more work is required to develop the required institutional frameworks and effective legislation to promote the successful implementation of the WSUD philosophy.

Table 6.1: Summary of local authority legislation relating to managing wastewater streams and water conservation

Local Authority	Policy/Bylaw	Status	Overview
City of Cape Town	Industrial Effluent and Wastewater By-Law	Adopted (CoCT, 2006a)	These by-laws focus on the appropriate management of the municipal sewer system. They discuss the duties and responsibilities of property owners, as well as the protection of municipal sewers. Issues such as discharge of particular substances, stormwater ingress, as well as regulations around the discharge of industrial effluent are also covered.
	Treated Effluent By-Law	Adopted (CoCT, 2009c)	The purpose of the by-laws as stated in the preamble is "*To control and regulate treated effluent in the City of Cape Town; and to provide for matters connected therewith*". They include a chapter on the provisions relating to the supply of treated effluent, as well as the installation, health and hygiene, and water quality requirements. They are particularly useful in promoting the re-use of wastewater at a broader scale.
City of Johannesburg	Water Services By-Law	Adopted (CoJ, 2008)	These by-laws contain a chapter on the appropriate management of the municipal sewer systems and include the duties and responsibilities of property owners, as well as the protection of municipal sewers. Issues such as discharge of particular substances, stormwater ingress, as well as regulations pertaining to the discharge of industrial effluent are discussed.
eThekwini Municipality	Sewage Disposal By-Laws	Adopted (eThekwini Municipality, 2013)	These by-laws focus on the effective management of the municipal sewer system. In addition they provide regulations around the use of treated effluent and the issues associated with the use of this resource.
	Guidelines for the monitoring and control of sewage disposal and treatment	Adopted (eThekwini Municipality, 2013)	In addition to the by-laws regarding the management of wastewater, eThekwini has produced a range of guidelines and policy relating to the management, and use of wastewater.
	Guidelines for the re-use of treated effluent from sewage treatment works	Adopted (eThekwini Municipality, 2013)	
	Guidelines for the submission of alternative on-site waterborne sanitation systems	Adopted (eThekwini Municipality, 2013)	

6.3 Institutional responses to WSUD in South African metropolitan municipalities

As previously described, WSUD represents a policy amalgam which is essentially composed of two parts: 'Water Sensitive' and 'Urban Design'. The dual character of the term reflects an expansion in its original conception from using stormwater drainage as a water resource (i.e. through concepts such as Sustainable Drainage Systems, SuDS), to assessing whether other municipal functions, such as urban design and planning, wetland conservation, water demand management and wastewater re-use could augment water security in the face of increasing and multiple demands through enhanced co-ordination and integration.

A study was undertaken to investigate the institutional arrangements with respect to WSUD in South African metropolitan local governments, and in particular to address the following questions: to what extent does the structure and functioning of urban water management give effect to the principles of WSUD? How is the management of urban water resources structured in municipalities, and what is the level and nature of cross-functional co-ordination and integration of activities between specialised departments responsible for specific components of water resource management? The objective of the study was therefore to try to translate the need for the physical imperatives of urban planning for sustainable water resource management into an assessment of the institutional arrangements that either facilitate or impede co-ordination and integration. These enablers and obstacles were assessed by examining: the institutional arrangements that metro local governments in South Africa have put in place to render urban planning; the various technical services involved in the delivery, storm and wastewater management; as well as environmental management services. The full report is provided in Appendix B, but the main findings are presented here.

6.3.1 Organisational arrangements for urban water management

The formal organisational arrangements in the four metropolitan municipalities of Cape Town, eThekwini, Johannesburg and Tshwane were assessed to determine how urban water systems are managed in these cities. The assumption that both core (e.g. supply, storm and wastewater) and ancillary (e.g. environmental management) urban water management functions are currently being 'compartmentalised' was confirmed in all four metros, albeit with some notable differences. In general, stormwater management is paired with roads and transport, which operates separately from the supply and treatment of water that is typically housed in a department of water and sanitation.

Related to the compartmentalisation of urban water management functions is the fact that it has side-lined the adoption of an ecological or environmental focus to engineering water services in these metros – even though there are generally some 'environmental management' roles within the metros. At a strategic level environmental management tends to function separately from the main water resource management functions – although it was observed that an 'environmental' focus has been incorporated directly into the stormwater management function in three of the four metros (excluding Johannesburg which has devised co-ordinating structures to link the two functions). This suggests that administrative arrangements have, in some measure, accommodated planning and implementation at a 'catchment' level to address ecological concerns. It was also clear that there is an increasing emphasis on augmenting the knowledge and skills of engineering staff to promote a more holistic (e.g. natural environment-oriented) approach to stormwater engineering in particular, informed by SuDS. This does not necessarily mean that structural integration at a line function level would provide the desired WSUD catalyst. Structural reform to drive WSUD is more likely to happen at a non-line function executive level ('higher up' the organisational chart) where it is driven from the level of a metro's executive or 'corporate' management, which could facilitate inter-departmental co-ordination and ensure that additional resources are earmarked.

6.3.2 Service-level responses to WSUD

In all four metros there was evidence of a response to WSUD principles at the level of individual service provision – including programmes to deal with urban water management aspects such as: Water Demand Management and Water Conservation (WC/WDM); improving poor river water quality through activities which minimise overflow from the sewer reticulation system into rivers; reusing treated effluent for potable use; the investigation of alternative water sources and the implementation of Sustainable Urban Drainage Systems (SuDS); and urban rainwater harvesting.

In order to be able to progress to a more co-ordinated service level response to WSUD, municipalities need to be able to exhibit varied levels of co-ordination ranging from limited interaction to more intensive attempts to co-ordinate functions to manage cross-sectoral water resource issues such as WSUD. Whilst there is evidence of municipalities responding to individual WSUD principles, however, this does not necessarily translate into corresponding levels of co-ordination and integration across water and other related services (such as Planning, Urban Design, Housing, etc.) within these cities. There is unrealised potential for more extensive co-ordination – which could be facilitated by urban and strategic planning fora. There were also examples of more extensive co-ordination, driven by the stormwater (through catchment management), as well as environmental management portfolios. Despite these concrete efforts, a number of constraints continue to impede their full potential – including a lack of enabling council-approved policy and guidelines (with political backing and the force of by-laws), and the need for interventions to effectively re-train (capacity-build) technical officials on water sensitive approaches. This reinforces the need for policy advocacy of SuDS and WSUD at an executive level, which could also facilitate political backing. In this regard, it may be more effective for metros to push WSUD as part of complementary initiatives that have greater and wider public and policy appeal, such as 'greening' initiatives which promote energy efficiency, as well as climate change mitigation.

6.4 Enablers and challenges to promoting co-ordination and integration in water services

To summarise, the following sections briefly summarise the various ‘enablers’ and challenges that have been identified as promoting and/or hindering coordination and integration in water services.

6.4.1 Enablers to facilitate greater coordination & integration

- Increasing emphasis on re-use of water / wastewater.
- Increasing sensitivity to monitoring water quality.
- Strategic clustering of functional activities within metros can potentially spur on more substantive co-ordination and integration of water services.
- Protection of urban catchments (i.e. spatial focus) can facilitate functional co-ordination.
- Existence of auxiliary structures, e.g. those additional to traditional line function structures, such as special forums and committees, can potentially facilitate co-ordination and integration.

6.4.2 Challenges facing greater co-ordination & integration

- Cost-recovery demands / pressures of water and sanitation (reticulation services) can hinder the pace of coordination and integration with other water services functions.
- The synchronising of planning at a city-wide level (e.g. strategic, spatial) with infrastructure planning being carried out at a line-function level (e.g. in water services departments).
- Delays in finalising planning and regulatory instruments with legal force can inhibit the potential for cross-departmental co-ordination and integration.
- Advocating WSUD principles in policies aimed at retro-fitting existing settlements, especially those targeted for municipality-financed low-cost housing will be confronted by challenges of density, scale of demand and political sensitivities concerning the perceived quality of the engineering options they represent.

7. Discussion and conclusions

South Africa is a 'developing country' still facing the challenge of providing basic services, in particular water, to a significant proportion of the population, whilst a minority are fully serviced to standards equal to any 'developed' nation. Water security is increasingly a matter of major concern, with most surface water resources fully accounted for and poor water quality within and downstream of urban areas. RSA is, partly as a result of its Apartheid history, one of the most 'unequal' countries in the world as illustrated by its Gini coefficient ranking of 0.631 (World Bank, 2013). Whereas service delivery and social upliftment are high on the political agenda, the challenge is to promote economic and social equity whilst simultaneously ensuring environmental sustainability; and this challenge is greatest in the rapidly growing urban areas. It is postulated that from a water management perspective, this will require the adoption of WSUD in an attempt to achieve the ultimate goal of WSSs. This report has attempted to define what 'water sensitivity' means within the complex developmental context of RSA and highlights that it is only through the effective integration of urban design, planning and management undertaken in a water sensitive manner that the WSS goal will be realised.

The NDP sets a broad strategy and a number of ambitious goals for the development of a desirable future for RSA. Water is one component, but the document does not, and is not meant to, deal with the details of managing water. It does however include the provision of affordable, sufficient and safe water to meet the needs of the population while ensuring limited negative environmental impacts. The NWRS-2 addresses many of these goals from a national perspective and provides a strategy for managing the water resources of the country at a catchment scale (through the implementation of catchment management agencies). It does not, however, deal with nor set a vision for the management of water within an urban setting. The four-component framework that has been developed as part of this research focuses specifically on urban water management – a sector which is inadequately dealt with in the NWRS-2 – and sets a vision for transforming RSA's towns and cities to be water sensitive in line with the ideals of both the NDP and NWRS-2. In future revisions to the NWRS-2 the Framework should be incorporated and a greater focus should be placed on urban water management.

Locally-relevant information on the individual technologies and BMPs associated with WSUD is generally available and well-documented. What is not so apparent in the RSA context however, is the way in which the notion of water sensitivity links with urban design and planning, and how the concept of WSUD / WSSs can be used to transform towns and cities in RSA. The sustainable management of water has the potential to bring about a positive change in urban areas in many other ways; e.g. lowering temperatures in respect of climate change adaptation and mitigation. Conserving potable water resources also means that there will be water available for other productive uses; this has socio-economic implications and ensures greater equity in terms of the availability of a wider variety of water services. In the South African context, where cities have largely been shaped by the legacy of apartheid, WSUD also has the potential to 'connect' spatially-divided communities and settlements through linking open spaces and promoting these spaces to showcase water; providing blue-green infrastructure; and creating ‘liveable’ cities. WSUD also offers a host of options for new innovations, techniques and technologies which could offer potential for the commercialisation of products, thereby enhancing job creation and contributing to the green economy. However, engineers and technologists can only take the notion of WSS so far – sociological, planning and urban design aspects must also be included, as well as the way in which the WSUD message is conveyed. It is postulated that if the required planning is achieved at an overarching level, then WSUD will automatically be incorporated. A useful question is then “How can the WSUD philosophy be used to integrate water into urban design so as to bring about fundamental change in South African communities?” This will only be progressively answered once there are sufficient South African case study examples to highlight the change in urban water management from ‘business as usual’ to one where cities can effectively be transformed.

Whilst the Framework is specifically geared for the RSA context, the lessons learnt and approach used could be widely applied in other developing countries facing similar challenges (e.g. limited capacity, limited resources) where the setting up of conventional LAs, demonstration projects, and importing of skills is not always possible. Ideally all urban areas should be ‘water sensitive’ but what this means in different country contexts is important and as such, defining key terms within the context is crucial. Context is also vitally important when identifying opportunities to ‘leapfrog’ development stages and determining how this may be achieved. For example, in certain contexts ‘leapfrogging’ may be technically possible but not socially acceptable. Brown *et al.* (2009) claim that there are currently no examples of a truly water sensitive city anywhere in the world. This raises the question of whether the vision of a WSC and WSSs is a realistic one for RSA. On the other hand, whilst it may not seem to be wholly achievable, it should be remembered that it is a long-term vision with no specific deadline for implementation. Having this vision means that, as far as possible, and within the means available, decision-makers in RSA towns and cities are encouraged to continuously improve the management of their urban water systems with a view to transitioning ‘closer’ to the ideals of water sensitivity. This will ensure that alternatives to conventional urban water management will always be considered.

As RSA continues to face the challenges of water scarcity and declining water quality, the relevance of WSUD will increase and the need to start considering cities in a different way will become more and more urgent. The challenge of creating sustainable cities incorporates far more than the water management paradigm; it is critical that the management of water is integrated with other urban functions such as energy, land use, transport and solid waste in order to align with the broader objectives of creating more sustainable urban environments. The proposed four-component framework for achieving WSSs provides a way forward in this regard. The research component can be used to build the knowledge and capacity required to adopt the long-term vision, while the narrative sets the scene for engaging with stakeholders and decision-makers in an effort to manage the challenges facing the country’s urban water sector. The implementation component addresses the trade-offs that may be required in determining the best use of resources for developing multi-functional urban areas that are resilient and adaptable to change, as well as addressing development and equity issues.

8. Recommendations for a way forward

There is a need for national government to offer guidance, capacity and policies to support local authorities in the planning and design of urban settlements. The Framework – were it to be adopted as the vision for managing urbanised areas in RSA – is the first step. It sets the vision and addresses how RSA can move forward in terms of achieving this vision. It offers a means to improve the protection and restoration of urban environments; to safeguard water security; to enhance public health and economic sustainability in the urban setting; to increase social and institutional investment into urban water management; and to actively lead in exploring a suite of appropriate, sustainable social technologies in a transition to water sensitive settlements. The NDP, NWRS-2 and Framework all provide input into the management of water resources in RSA. Together these documents could provide a comprehensive vision for the future management of water resources in RSA. The merging of the NWA and the NWSA (policy review process currently underway) may also offer an opportunity to bring WSUD into legislation. Consultation with the relevant authorities at national government level will be necessary to take this further and to gain their acceptance of the WSUD vision.

In order to develop and entrench an overall vision for WSS in South Africa, opportunities for piloting WSUD implementations, both at catchment and site-scale, should be pursued. It is critical, however, that WSUD principles are embedded in catchment management plans and stormwater master plans first so that local authorities can start planning holistically for a transition to WSSs. Once the planning at the catchment scale has been resolved, the adoption of development-level WSUD strategies can be initiated. These pilot implementations will start contributing to a WSUD community of practice in South Africa in order to: build the case for this changing paradigm in urban water management; start addressing the necessary regulatory changes for wide scale adoption and implementation; and to engage developers in a broader understanding of the concepts of green infrastructure (i.e. not only energy efficiency).

It is important that the profile of WSUD and SuDS is increased amongst the engineering fraternity, as well as with national and local government officials, planners, developers, etc. One of the ways of ensuring this is to establish Learning Alliances (LAs) in different towns / cities in order to link the various stakeholders in these urban water systems and promote shared learning and innovation around sustainable water management practices. Skilled facilitators will be required to assist in the effective running of these LAs and to ensure the resultant outcomes in terms of policy and impacts. Another way of disseminating information on WSUD would be to develop a hands-on, practical manual on how to bring WSUD into existing and new developments

PART 2

WSUD Guidelines

9. WSUD activities

WSUD is an effective tool for advancing the principles of sustainable development within the urban water management discipline – focusing on the interaction between the urban built form and water resources management (Wong, 2006b). The overarching theme of WSUD is ecologically sustainable development; by considering all aspects of the water cycle and their interaction with urban design, it aims to be the medium through which sustainable development can achieve sustainable urban water management. WSUD brings together a range of activities under one umbrella, as detailed in previous sections (for example, as per Figure 3.1). The two main components of WSUD – urban water infrastructure and design & planning – are shown in Figure 9.1. This section does not deal in detail with the design and planning aspects of the WSUD approach as this was beyond the scope of the report – but rather provides an illustration of the types of infrastructure-related activities that can be implemented as part of WSUD.

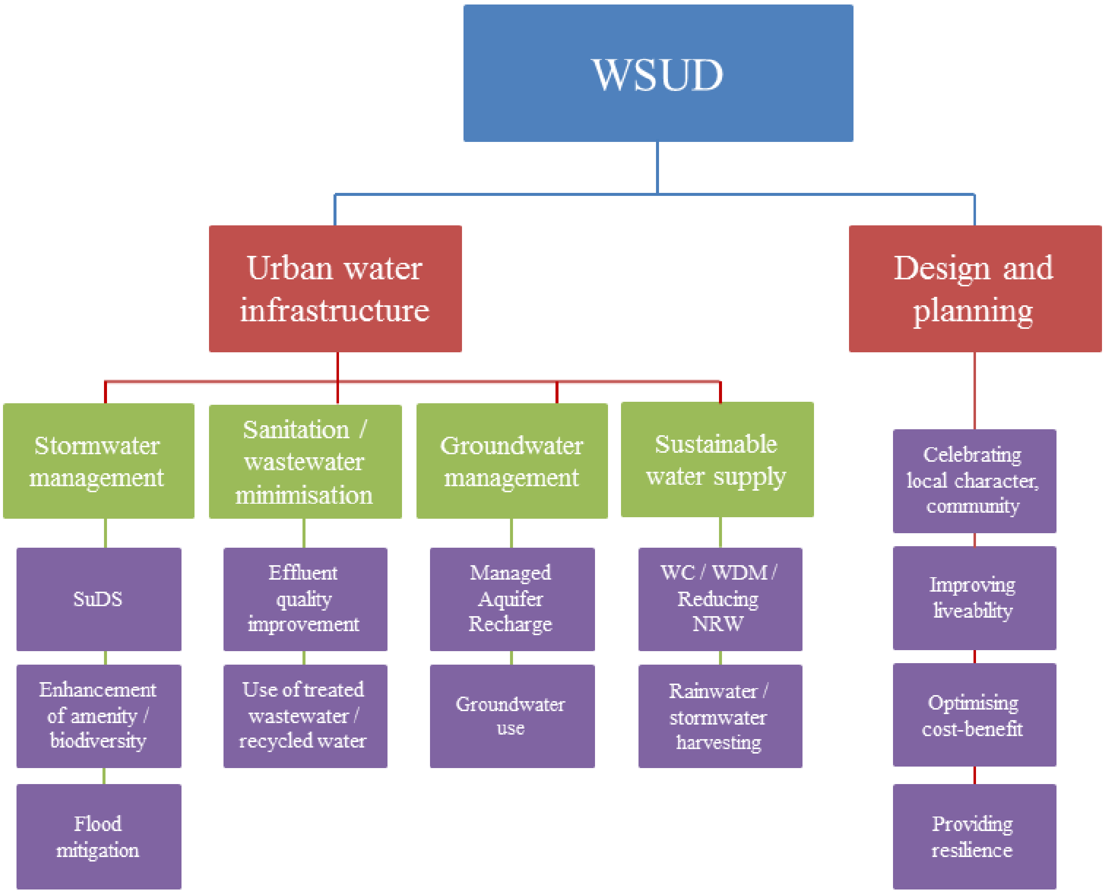


Figure 9.1: WSUD activities

Further detail on the WSUD-related activities associated with these two main components is provided as follows:

1. **Urban water infrastructure –** all infrastructure elements of the water cycle considered concurrently so as to sustain the environment and meet human needs:
    - Stormwater management – taking a SuDS approach which incorporates elements such as the enhancement of amenity and biodiversity, and flood mitigation.
    - Sanitation / wastewater minimisation – including effluent quality improvement, and use of treated wastewater / recycled water.
    - Groundwater management – including artificial recharge, use of groundwater.
    - Sustainable water supply options – including water conservation (WC) / water demand management (WDM), reduction of NRW, alternative water sources, e.g. rainwater / stormwater harvesting.

2. **Design and planning –** consideration of the water cycle throughout the design and planning process:
    - Celebrating local character, environment and community.
    - Optimising cost-benefit of infrastructure and built form.
    - Improving liveability.
    - Providing resource security and resilience.

Whilst these areas / activities in which WSUD can be expressed are often dealt with separately by different professionals, the holistic approach emphasised by WSUD requires that they be considered simultaneously. As is evident, there are a wide range of urban water infrastructure strategies which can be used to effectively incorporate WSUD into planning and design. These strategies adopt a variety of Best Management Practices (BMPs) and Best Planning Practices (BPPs) to fulfil the objectives of total water cycle management (Water by Design, 2009). It should be noted that the four streams (stormwater, wastewater, groundwater and water supply) of the urban water cycle are intricately linked; different technologies and strategies apply to each of the streams with several strategies applying to one or more of the streams. The streams may interact through a number of WSUD activities, the ultimate goal being the holistic management of the urban water cycle to simultaneously achieve the desired economic, environmental, and social benefits. Examples of some of the areas where WSUD could be considered apply to each of these streams; i.e. stormwater management, sanitation / wastewater minimisation, groundwater management, and sustainable water supply are described more fully in the following sections of the report.

Further information on urban water infrastructure activities which incorporate WSUD aspects can be found in several well-documented and researched manuals and guidance documents which have been published internationally in recent years – links to three of the most relevant of these documents have been made available at www.wsud.co.za as follows, but are also available through the references provided:

i) City of Melbourne Water Sensitive Urban Design Guidelines (City of Melbourne, 2009).

ii) Water Sensitive Urban Design – Principles and inspiration for sustainable stormwater management in the City of the Future. (Hoyer *et al*., 2011).

iii) blueprint2013 – Stormwater Management in a Water Sensitive City (Wong *et al*., 2013).

10. Stormwater management – Sustainable Drainage Systems (SuDS)

There has been growing interest in the promotion of sustainable development amongst local and national governments throughout the world – and this includes the control of stormwater runoff (Ellis *et al.*, 2006). South Africa's first Guidelines for Sustainable Drainage Systems have recently been published by the South African Water Research Commission (Armitage *et al*., 2013).

Sustainable Drainage Systems (SuDS) offer an alternative approach to conventional drainage practices by attempting to manage surface water drainage systems holistically in line with the ideals of sustainable development. They achieve this by mimicking the natural hydrological cycle, often through a number of sequential interventions in the form of a 'treatment train'. The key objectives of the SuDS approach include: the effective management of stormwater runoff quantity and quality, promoting the amenity value, and the preserving / encouraging biodiversity value. This may be described in the form of a hierarchy (Figure 10.1) where each level contributes to an improved, more sustainable drainage system. Simply put, there is no point focusing on biodiversity if life and property have not already been protected.

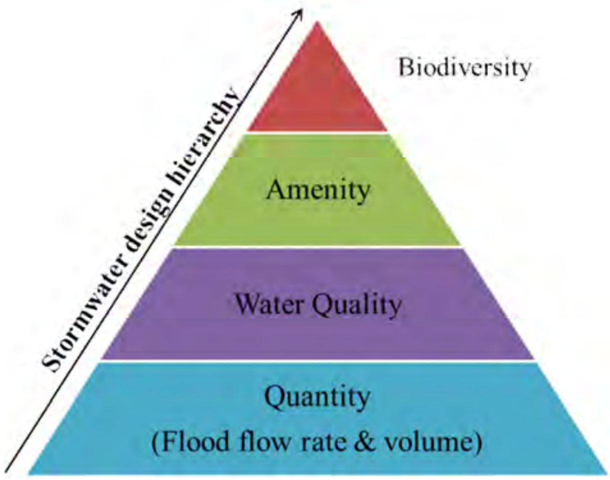


Figure 10.1: The stormwater design hierarchy

Prior to the design of any stormwater system there are a number of important factors to be considered, each of which is discussed in further detail in the RSA SuDS Guidelines document:

- The local hydrological cycle.
- The local ground conditions – including unusual geological formations.
- The different challenges of development on greenfield *vs*. brownfield / retro-fitted sites.
- The impact of different types of development.

- Compliance with the law – particularly local by-laws which are often quite specific with respect to allowable development.

10.1 Urbanisation and the water cycle

"*Urbanisation affects many resources and components of the environment in urban areas and beyond* (Marsalek *et al.*, 2008)". Water is just one of the resources affected. The 'water cycle' has "*been used to represent the continuous transport of water in the environment*" (Mitchell *et al.*, 2001). Urbanisation results in the natural water cycle being altered (AMEC Earth and Environmental *et al.*, 2001), as highlighted in Figure 10.2.

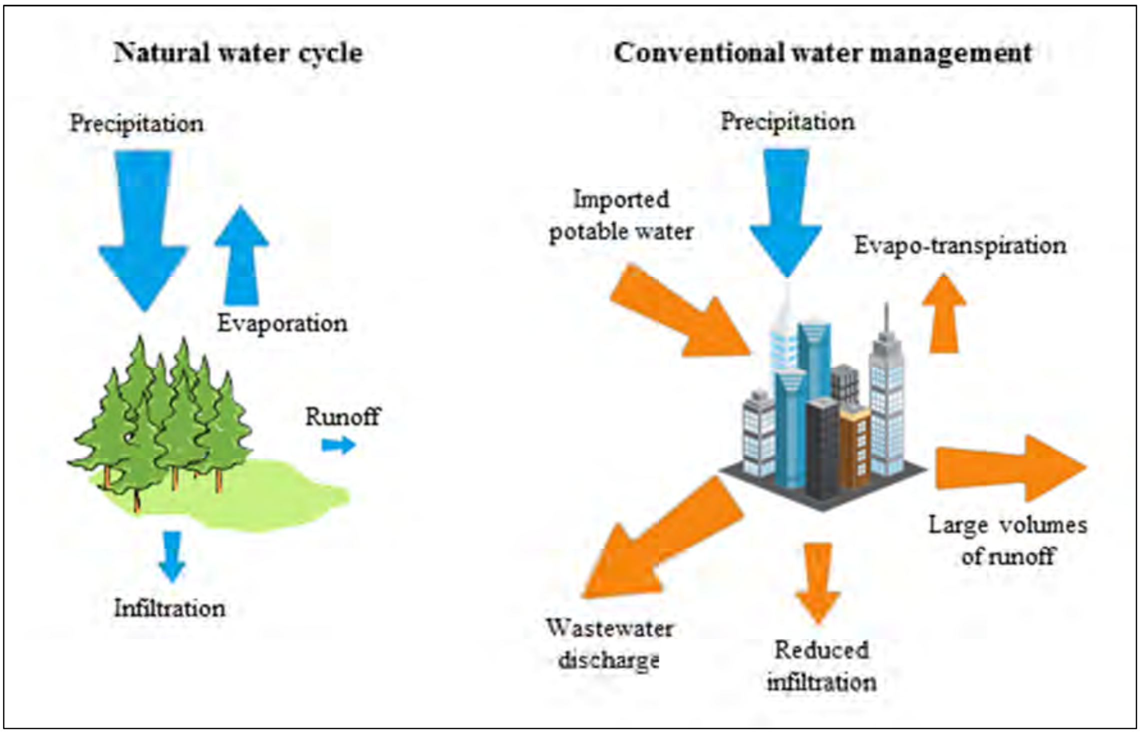


Figure 10.2: Urban water cycle showing changes to the natural water cycle with traditional urban development (adapted from Hoban & Wong, 2006)

Figure 10.2 shows the differences between the natural and urban water cycles. Marsalek *et al.* (2008) broadly summarised the impact of conventional stormwater management as follows:

- **Reduced infiltration** – results in a decrease in infiltration which in turn decreases groundwater recharge while increasing runoff volumes and peak flows (AMEC Earth and Environmental *et al.*, 2001).
- **Changes in runoff conveyance networks** – "*as the urbanising area develops, there are profound changes in runoff conveyance, by replacing natural channels and streambeds with man-made channels and sewers* (Marsalek *et al.*, 2008)."

- **Increased water consumption** – "*urbanisation results in a population increase, and in most cases, an improvement of sanitation* (Marsalek *et al.*, 2008)." Since water used indoors is often disposed of via the wastewater system there is also generation of wastewater which is treated and then released to receiving water bodies.

Urbanisation results in wide-scale changes to the water cycle, especially in terms of how water is drained. These changes have significant environmental impacts. As a result it is widely accepted that a new, integrated approach to urban water management is required (Brown *et al.*, 2009; Marsalek *et al.*, 2008; Mitchell *et al.*, 2001; Wong & Brown, 2008). SuDS, as the urban drainage component of Water Sensitive Urban Design (WSUD) offer a holistic approach to drainage in the urban environment.

10.2 SuDS selection

It is important to understand that SuDS generally embrace a number of options that are arranged in a treatment train. In other words, stormwater is managed through a series of unit processes in much the same way as, for example, wastewater is treated in a treatment works. The different SuDS options have been categorised into twelve 'families' in the RSA SuDS Guidelines (Armitage *et al*., 2013); a summary of each of these is presented in this report. They all incorporate a variety of treatment processes with considerable overlap. The linking of these processes in the form of treatment trains is important as it ensures the resilience of a SuDS drainage system. The selection of any particular option is determined by the unique characteristics of the site. It is unlikely that all options will be applicable and/or effective on any one site. It is thus important that the advantages and limitations of each option should be identified during the planning and design phases. Wilson *et al.* (2004) and Woods-Ballard *et al.* (2007) identify seven basic selection criteria in this regard:

i) Current and future land use characteristics.

ii) Site characteristics and utilisation requirements.

iii) Catchment characteristics.

iv) Stormwater runoff quantity (peak flow and flood volume) requirements.

v) Stormwater quality requirements.

vi) Amenity requirements.

vii) Biodiversity requirements.

Appendix G of the RSA SuDS Guidelines provides a '*SuDS Conceptual Design´* matrix that may be used in the design process to identify the most appropriate technology for a specific use based on a range of criteria.

10.2.1 SuDS treatment train

There are four key intervention points ('coaches') in the SuDS treatment train (Figure 10.3), each having slightly different combinations of SuDS options to control and/or manage stormwater:

i) **'Good housekeeping'** to ensure that as much as possible is done to minimise the release of pollutants – such as solid waste – into the environment where they may subsequently be transported by stormwater.

ii) **Source controls** manage stormwater runoff as close to its source as possible, usually on site. Typical SuDS options include: green roofs, rainwater harvesting, permeable pavements and soakaways.

iii) **Local controls** manage stormwater runoff in the local area, typically within the road reserves. Typical SuDS options include: bio-retention areas, filter strips, infiltration trenches, sand filters and swales.

iv) **Regional controls** manage the combined stormwater runoff from several developments. Typical SuDS options include: constructed wetlands, detention ponds and retention ponds.

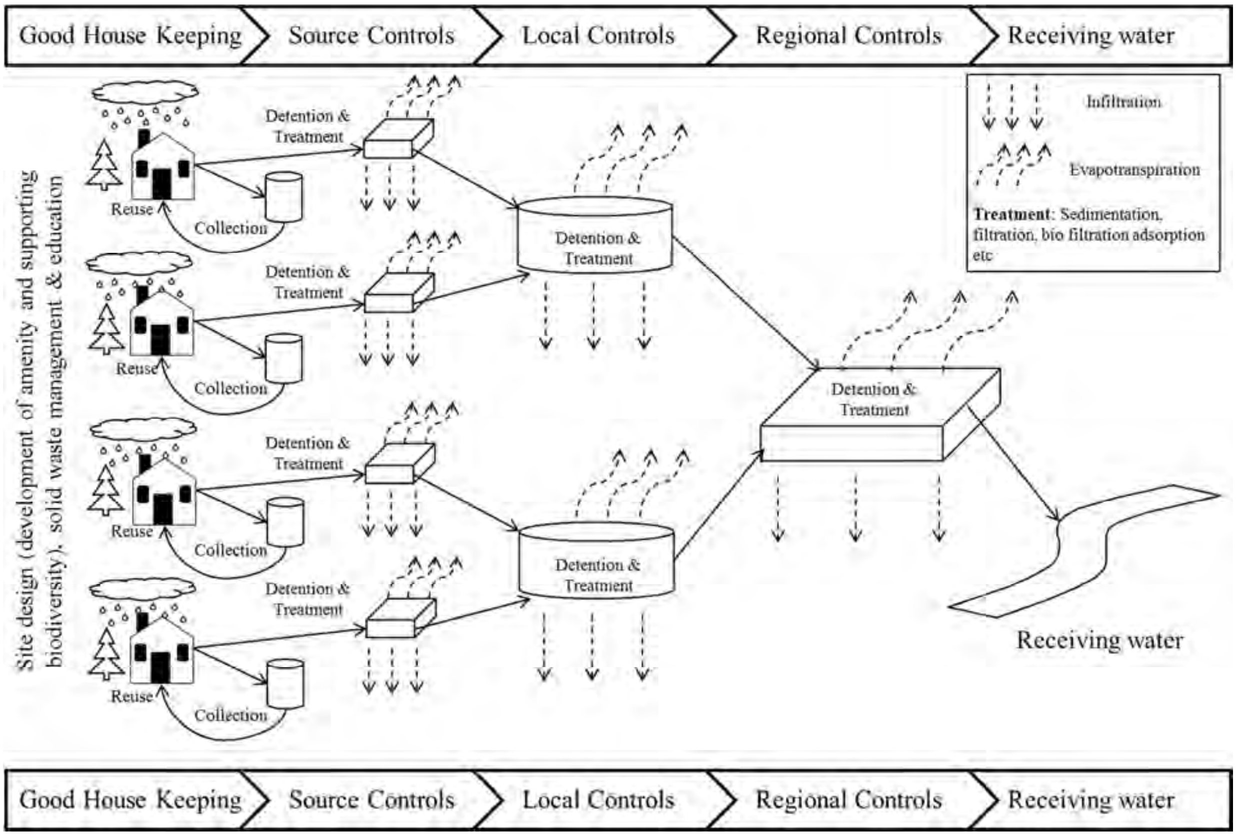


Figure 10.3: SuDS treatment train schematic

Figure 10.3 depicts a SuDS treatment train illustrating the relationship between the four SuDS interventions. Treatment trains should prioritise: (1) water quality treatment for low flows; and (2) attenuation and volume control for high flows. Furthermore, the number and size of the SuDS treatment train components depends on the following (Woods-Ballard *et al.*, 2007):

i) The sensitivity of receiving watercourses or other environments.

ii) The size of contributing catchments upstream.

iii) The expected pollutant concentrations in stormwater runoff inflows.

Whilst the different SuDS options tend to be associated with particular points in the treatment train, it is often possible to utilise them elsewhere depending on the site. For example, constructed wetlands are generally regarded as a regional control but they may also be used as an effective source control, as in the form of a pocket wetland in a residential complex.

10.2.2 Overview of SuDS options

It is important to recognise that certain SuDS options may be inappropriate under certain conditions found in South Africa. The advantages and limitations of each alternative system should be identified during the planning and design phases (Donovan & Naji, 2003; Melbourne Water Corporation, 1999). The South African SuDS Guidelines group the different SuDS options according to the scale at which they are most likely to be used – Figure 10.4.

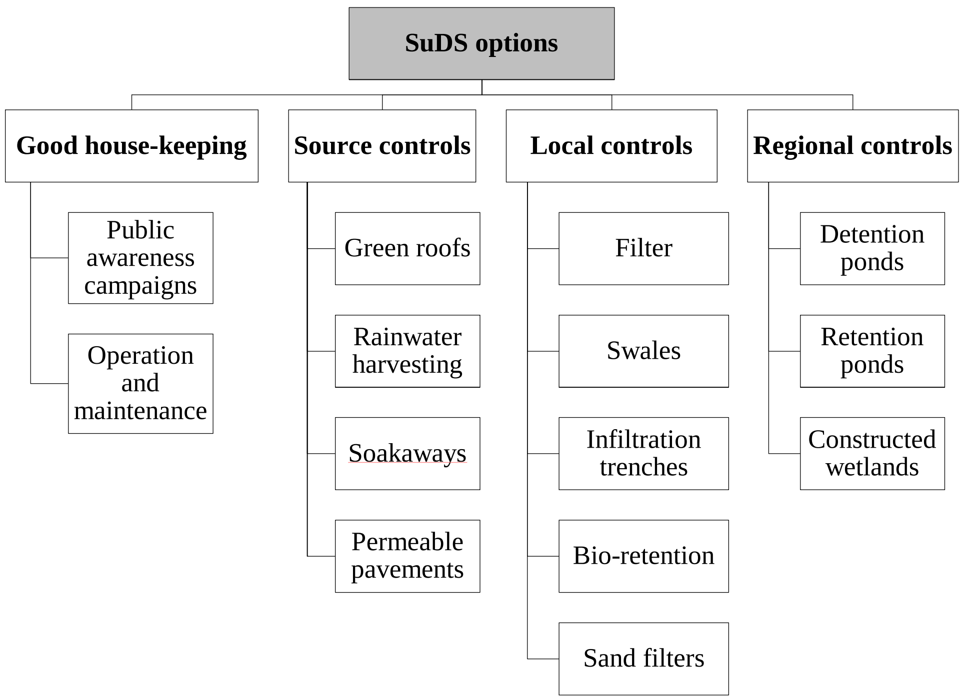


Figure 10.4: RSA SuDS Guidelines – grouping of SuDS options

The grouping shown in figure 10.4 does not prevent the use of different options at different scales. SuDS are not meant to be stand-alone interventions. For any given development, a number of SuDS options are usually – and should be – grouped together in the form of a treatment or management train. The components of the SuDS treatment train are discussed in detail in the RSA SuDS Guidelines document (Armitage *et al*., 2013).

10.2.3 Stormwater harvesting

Stormwater harvesting is "*the collection, treatment, storage and use of stormwater run-off from urban areas*" (DECNSW, 2006). The RSA SuDS Guidelines are focused on stormwater management only, and not on opportunities for integrating the management of stormwater runoff with water supply. They therefore do not consider rainwater harvesting at the source level. It should be noted however, that at the local / regional level it is also possible to harvest stormwater for use while simultaneously managing stormwater. The following section briefly outlines the different options for stormwater harvesting. Further information on the use of rainwater / stormwater as an alternative water source may be found in Section 13.5.1.

There are a range of options for harvesting stormwater. For this report three options are discussed: tank storage, open storage, and managed aquifer recharge. The options apply at different scales and depend on the intended applications for the harvested water. All designs need to consider the following (DECNSW, 2006):

- How the water will be collected?
- Where it will be stored?
- The need and options for treatment?
- How it will be distributed for its end use?

10.2.3.1 Tank storage (predominantly used for rainwater harvesting)

In Australia, tanks are the most widely used form of storage for rainwater (Hatt *et al.*, 2006). Tanks may be used to store rainwater that runs off a single roof or a number of roofs (Begum *et al.*, 2008; Hatt *et al.*, 2006). Most commonly, tanks are used to collect the runoff from a small catchment, e.g. a single roof, owing to their limited storage capabilities. It is therefore not surprising that as the catchment size increases the use of tanks decreases (Hatt *et al.*, 2006).

There are a number of variations of tank storage which include aspects such as greywater usage and water treatment, e.g. as described in 'The Sustainable Home Water System' (CMHC, 2002). A selection of the major advantages and disadvantages of using tanks to harvest rainwater are provided in Table 10.1.

Table 10.1: Advantages & disadvantages of rainwater tanks

Advantages	Disadvantages
Mosquitoes can easily be managed if proper screens are installed (NRMMC *et al.*, 2008).	Roof materials may leach toxins (NRMMC *et al.*, 2008; RainWater Cambodia, 2011).
Managing at source helps mitigate the negative impacts of urbanisation on water quality and flow (Fletcher *et al.*, 2008; NRMMC *et al.*, 2008).	"*Anaerobic conditions can develop in stormwater storage tanks where the stormwater has high levels of organic matter and the residence time is long…can lead to odour problems* (NRMMC *et al.*, 2008)."
Tanks are widely available in South Africa (Armitage *et al.*, 2013)	Relatively expensive means of harvesting and reusing stormwater (Armitage *et al.*, 2013; Marsden Jacobs Associates, 2006).

10.2.3.2 Open storage

Open storage stormwater includes "*ponds, dams, constructed lakes and open water bodies such as lakes, rivers, streams and creeks* (Goonrey, 2005)." The use of natural water bodies such as existing wetlands should be carefully considered to prevent irreparable damage as a result of pollutants (Armitage *et al.*, 2013). Figure 10.5 shows the conceptual design of an open storage system, e.g. a retention pond.

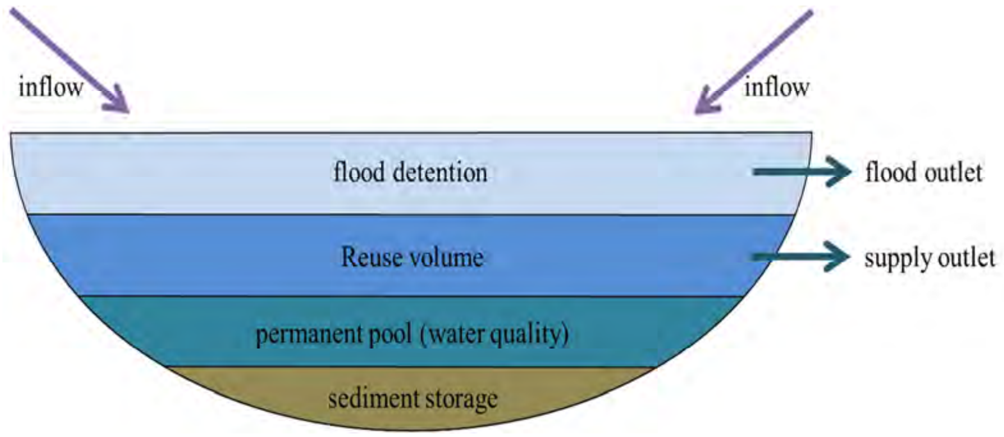


Figure 10.5: Conceptual design of an open storage stormwater harvesting and re-use system (after DECNSW, 2006)

Open storage systems are attractive to a range of fauna including water birds, the faeces of which may result in increased pathogen levels which may be a public health concern (Armitage *et al.*, 2013; DECNSW, 2006). If well designed, they are known to offer a range of benefits, such as increased property values, the provision of recreational areas, etc. Some of the advantages and disadvantages of open storage systems are shown in Table 10.2.

Table 10.2: Advantages & disadvantages of open storage

Advantages	Disadvantages
Low capital and maintenance costs, ease of construction (Goonrey, 2005)	Public safety
Provides ecosystem goods and services	Public health threat from, e.g., mosquitoes
Aesthetics: if properly maintained may be an advantage, if not maintained will be a disadvantage	

10.2.3.3 Managed Aquifer Recharge

Managed Aquifer Recharge (MAR) is the intentional collection and recharge of water to aquifers. The purposes of managed aquifer recharge may vary from storage for future re-use to maintenance of the ecological reserve (NRMMC *et al.*, 2009). The Atlantis Water Resource Management Scheme is an example in South Africa of infiltration ponds having been used to recharge an aquifer for use at a later stage (DWA, 2010a). There are a number of different approaches that may be used to recharge an aquifer. Which approach is the most appropriate will depend on the characteristics of the aquifer, in particular whether it is confined or unconfined. Owing to the fact that there are a range of options for aquifer recharge, it is not possible to review each in detail. A number of general advantages and disadvantages of MAR have however been highlighted in Table 10.3. A more detailed description of MAR is highlighted in section 12.3 and the range of alternative approaches is illustrated in Figure 12.2.

Table 10.3: Advantages & disadvantages of Managed Aquifer Recharge

Advantages	Disadvantages
Limited space required (DECNSW, 2006).	Can potentially pollute aquifers (DECNSW, 2006; MBWCP & WBMOEE, 2006; NRMMC *et al.*, 2009).
Prevents salt water intrusion resulting from over abstraction (DECNSW, 2006).	
Extended retention times and filtration result in the removal of many pathogens (NRMMC *et al.*, 2009).	Requires suitable geology (DECNSW, 2006; MBWCP & WBMOEE, 2006; NRMMC *et al.*, 2009).
Generally the most cost effective option when geology is suitable (Wong *et al.*, 2013).	
Offers a number of ecosystem goods and services which may result in increased property values, decreased downstream flooding, etc. (NRMMC *et al.*, 2009)	Cannot be used in areas with shallow unconfined aquifers (NRMMC *et al.*, 2009).

10.2.3.4 Health risks of stormwater harvesting

Stormwater is a natural asset and this water should be regarded as an essential part of the recharge of the water supplies of a city (Haskins, 2012). Stormwater harvesting is a viable means of managing stormwater runoff and improving water security for many urban areas in

South Africa, and there are a number of examples from across the country that illustrate stormwater runoff being harvested from, e.g. large parking lots and commercial properties. However, the risks associated with poor water quality (e.g. the spread of disease / *E. coli* infections, vector control, etc.) need to be managed.

Precipitation in the form of rain during a storm event usually contains very little contamination, but this changes drastically once the rainwater hits urban surfaces where it may pick up large pollution loads. Urban stormwater runoff is an important conduit of microbial pathogens and other hazardous substances (Marino & Gannon, 1991; Sidhu *et al*., 2012), and has the potential to disseminate diseases quite widely given that the destination of much of the urban stormwater is the nearest river or other watercourse such as lakes and marshes / wetlands. In spite of the fact that urban stormwater is one of the largest sources of contaminants to surface waters, the fate and transport of these contaminants (especially microbiological pollution) have received little attention at operational level (McCarthy *et al*., 2012), particularly where stormwater flow emanates from areas with suboptimal sanitation; e.g. informal settlements.

The characteristics of the catchment area influence the types of microbiological pollutants entering the stormwater system; particularly larger urban catchments which generally have more complex stormwater infrastructure and thus more variable pollutant sources (Rauch *et al*., 2012). The microbiological pollution most often found in urban stormwater emanates from failing / non-existent sanitation systems as well as inappropriate waste disposal and hygiene habits, with the single most frequently encountered pollutant being raw sewage, followed by household greywater (sullage). The presence of sewage and polluted greywater (food remains, fats & greases, animal blood / tissue, etc.) in stormwater systems provides a breeding ground for human disease-causing organisms (pathogens) to multiply, and attracts disease vectors like flies, rats and mice and cockroaches (Nwaka, 2005). Sewage furthermore contains high concentrations of nutrients such as nitrates and phosphates which can cause algal blooms and build-up of toxins in water bodies receiving the stormwater. Meanwhile, solid waste in the form of urban litter causes blockages in the stormwater system and provides a 'trap' for food remains and sewage to accumulate and the pathogens to multiply. In addition, blocked drains cause sewage-laden stormwater to remain in and around living environments, thereby increasing the health risks.

10.3 The economics of stormwater management

SuDS are relatively new to South Africa. As with many new technologies of this type there is a degree of scepticism about local applicability (CIWEM, 2005). This is partly due to a concern about maintenance and associated costs for which there is a general lack of data worldwide (Taylor & Fletcher, 2006) and, to complicate issues further, local conditions will influence costs. On the other hand, there are also ‘hidden’ externalised costs associated with conventional drainage systems which need to be taken into account. This section reviews the international experience with respect to SuDS and also discusses the value of Ecosystem Goods and Services (EGS) which are provided by this approach.

10.3.1 International experience

SuDS technologies have been extensively implemented in a number of developed countries and various studies have been undertaken to assess the economic implications. A summary of some of the conclusions is presented in Table 10.4. Note that LID (Low Impact Development) and WSUD (Water Sensitive Urban Design) are broadly equivalent to SuDS in the USA and Australia respectively. Overall, Table 10.4 indicates that SuDS are usually, but not always, 5-25% more economical than conventional systems on the basis of Life Cycle Cost Analysis (LCCA). In some cases, conventional systems can cost twice that of the SuDS equivalent over the lifetime of the project. It is however important to identify 'who pays for what'. SuDS require on-going maintenance so a relatively higher proportion of the LCCA cost is contained within this activity. It is also important to recognise that these studies are not a case of two identical sites being developed; rather they usually consider a hypothetical alternative to design actually being implemented. Consequently there is uncertainty in some of the contingency values which could make a difference of 10-30% either way. Furthermore the experience of both designers and contractors will influence the economics of a design (Lampe *et al.*, 2005) – which is of particular relevance in South Africa where there is little experience with the planning, implementation and management of SuDS.

Table 10.4: Studies comparing SUDS and conventional systems

Study	Conclusions on the relative costs between SuDS and conventional systems
Boubli *et al.*, 2003	"*Based on the above discussion it appears that a WSUD can be delivered on most projects without imposing a cost burden. In fact a balanced WSUD may be cost neutral on smaller projects but is likely to deliver increasing savings on larger projects*."
Lloyd, 2004	"*Bio-filtration systems provide a 25% saving to the community compared to treating runoff conventionally at a downstream constructed wetland. Additionally research found 85% of homebuyers supported the introduction of this technology in their neighbourhoods.*"
Coombes, 2004	"*The benefits of WSUD source control approaches arise from reduced mains water use and reduced stormwater infrastructure…In addition, the case study demonstrates that use of WSUD source controls including rainwater tanks in new urban development's offers the economically most efficient infrastructure solution providing benefits to the community of up to $6B in the Lower Hunter Region and up to $5B in the Central Coast Region*."
Narayanan & Pitt, 2005	In a comparison of conventional systems and grass swales system, grass swales appeared to cost approximately a fifth of the cost over the life cycle.
USEPA, 2007	"*The 17 case studies presented in this report show that LID practices can reduce project costs and improve environmental performance. In most cases, the case studies indicate that the use of LID practices can be both fiscally and environmentally beneficial to communities.*"

A significant issue raised by some of the studies relates to the fairness of the comparison. It is important that economic analyses compare conventional and SuDS systems on an equivalent basis, the costs and benefits of each need to be considered. It is also important that the proposed SuDS system is realistic, and could be implemented. For example undertaking an analysis where the SuDS system comprises of unrealistically large swales would not result in a realistic analysis and should thus be ignored.

The discount rate is also an issue that is seldom considered in any of the studies. Varying the discount rate alters the economic viability of each alternative (Sidek *et al.*,2004). The credibility of some of the international studies is thus questionable. For this reason, unless independent verification is possible, these sorts of studies can only give an indication of typical ranges of values. Meanwhile, few studies take into consideration that conventional systems and SuDS can only be truly compared if the value of Ecosystem Goods and Services (EGS) – preserved by SuDS but largely destroyed by conventional systems – are taken into account. Incorrect conclusions will be reached if a LCCA is conducted without considering the significant costs that are externalized onto the environment by conventional systems.

10.3.2 Ecosystem Goods & Services (EGS)

Ecosystem Goods and Services (EGS) refer to all of the benefits provided by ecosystem processes involving the interaction of living environmental elements (ASLA, 2008). The motivation behind the adoption of SuDS and their practical application can be linked to the way they preserve these benefits (both in terms of human livelihoods and ecological functioning) – which can also be monitored as performance criteria to indicate whether a SuDS treatment train is functioning properly. The objective of the SuDS approach is to protect, restore and improve the immediate environment through efficient and effective stormwater management (MBWCP, 2006).

The difference between Natural Assets (NA) and EGS requires clarification. NA are "*the stocks of environmental resources owned by*" an individual or institution, whereas EGS "*are the flows of benefits derived from these assets (the interest or services generated by the natural capital*" (De Wit *et al*., 2009). A SuDS design effectively reinvests in NA which results in increased 'interest' in the form of EGS. Unfortunately, when the relative costs of conventional stormwater systems and SuDS are compared, the focus is commonly on the monetary costs to stakeholders and not necessarily on a more balanced assessment of the different forms of (natural) capital. This is evident in the examples presented in Table 10.4 where monetary costs were considered over the project life cycle but no account was taken of the benefits provided by the ecosystem processes, i.e. EGS.

The Millenium Ecosystem Assessment (2005) approach is one way of achieving a more balanced assessment so as to take into account the benefits derived from NA. It provides a simple representation of the different ecosystem goods and services such as: provisioning, regulating, cultural and supporting goods or services (Figure 10.6).

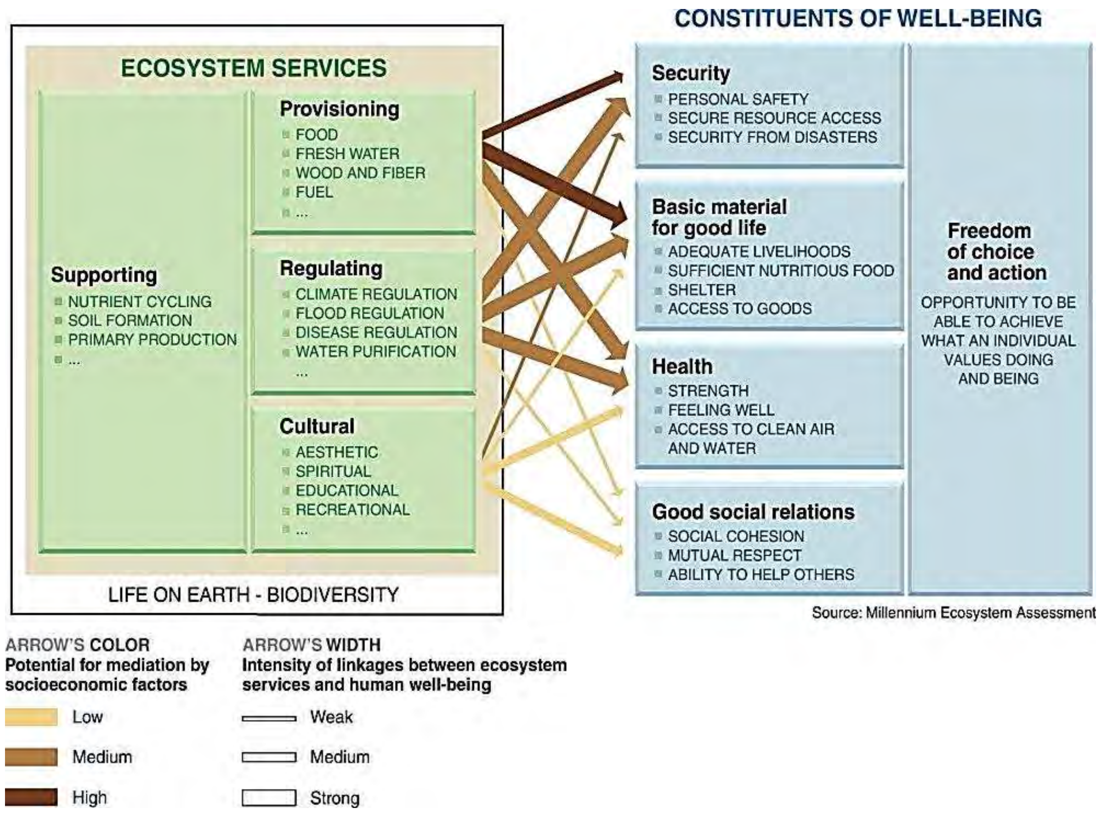


Figure 10.6: Ecosystem Services (Millenium Ecosystem Assessment, 2005)

Consideration of the ecosystems goods and services in these four groups assists in identifying possible valuation techniques and ensures that a service is not valued more than once when conducting an economic analysis. Most of the EGS provided by SuDS are classified as regulating services as these are most directly associated with stormwater management. The more important ones are highlighted in the descriptions that follow.

10.3.2.1 Reduced flooding

It is widely recognised that urban development generally results in increased runoff volumes and peak flows. Urbanisation can increase the runoff rate by 20-50% compared with natural conditions. In the extreme, the peak flow can be as much as 6.8 times that before development. This typically causes flash floods in streams and rivers and an increased number of 'bankfull' flows (SANRAL, 2007; Haubner *et al*., 2001; Brown *et al*., 2005). The SuDS philosophy of on-site treatment both promotes the retention of water on site and the reduction of runoff velocities. This reduces the costs and impacts on downstream infrastructure, e.g. bridges (ECONorthwest, 2007).

10.3.2.2 Improved water quality

Buys & Aldous (2009) noted that stormwater is a major contributor to deteriorating water quality in urban water systems. It is widely accepted that SuDS have the ability to treat stormwater and thereby improve water quality (ECONorthwest, 2007; Minton, 2002) by capturing pollutants and treating them through physical, chemical, and biological processes depending on the technology implemented. This improved water quality is an environmental service that is essentially provided for free. All 'natural' systems take time to break down microbiological pollutants and if the inflow into such systems brings more pollution than the system can treat, build-up will inevitably occur. It should therefore be borne in mind that the more polluted the stormwater, the higher the potential for the SuDS system to become overloaded which will result in significantly lower pollutant removal being realised.

10.3.2.3 Increased groundwater recharge

The South African Government has identified groundwater as an increasingly important resource, as almost all surface water resources around the country have been accounted for (Gosling, 2010). Urbanisation generally results in reduced infiltration which results in the lowering of the water table – which in turn results in increasing extraction costs and the potential for environmental damage. In Atlanta, USA, research carried out by Otto *et al.* (2002) suggests that impervious surfaces there have reduced groundwater infiltration by 132 billion gallons (500 billion litres) a year – the equivalent of 3.6 million people’s water usage (ECONorthwest, 2007). Conversely, in areas where there are high levels of leakage, groundwater recharge can be increased – this is likely the case in most South African cities where average levels of non-revenue water (NRW) are currently around 37%, a quarter of which can be attributed to physical leakage (McKenzie *et al*., 2012). Additionally, almost all SuDS promote infiltration thereby resulting in increased groundwater recharge.

10.3.2.4 Enhanced aesthetics & property values

Water frontage and the preservation of natural features can add to the aesthetics of an area and consequently to the value of local properties (US Department of Defense, 2004; ECONorthwest, 2007). ‘Properly designed’ drainage systems may have the ‘waterfront effect’ that is commonly associated with natural water bodies. The value of this typically ranges between 5 and 30% – averaging at a 10% increase in the value of those properties with a view of water bodies (Buys & Aldous, 2009). In Cape Town the rehabilitation of the Kuils River elevated property prices adjacent to the river by an average of 10-12% (Van Zyl & Leiman, 2001, in De Wit, 2009). A recently updated study by the US Department of Defense (2010) concludes that: “*In a variety of completed projects, micro-scale runoff management features have provided architectural interest in various forms*”.

This does not apply to all SuDS technologies as some may in fact cause depreciation in adjacent property values. Buys & Aldous (2009) found that dry ponds had the opposite effect to wet ponds and that property values were 4-10% lower next to these ponds. Detention ponds are frequently not properly maintained, collecting solid waste and other offensive material. Mosquitoes can present a health risk in wet areas. Additionally, certain options take up more land than conventional systems, and this land also has value (Buys & Aldous, 2009). On the other hand, some options like green roofs manage stormwater without requiring additional land (USEPA, 2000); an advantage for developers who are concerned about losing developable area. Table 10.5 is compiled from USEPA (1995) and indicates which factors relating to drainage tend to lead to an increase or a decrease in property values.

Table 10.5: Factors affecting property values (USEPA, 1995)

Factors affecting property values near open water bodies	
Increase	**Decrease**
Naturally designed water bodies (Wet ponds)	Open, unprotected water is a concern to residential owners with young children – drowning hazard
Ponds & lakes create ideal scenery for business parks	Poor design / aesthetic appeal (particularly dry ponds)
Positioning water features near entrances increase sale and value of properties	Safety concerns are the main negative effect of stormwater controls
Property with water views or other amenities can be charged premiums	Poor maintenance leads to unsightly wet / dry ponds due to excessive algal growth or garbage build-up
New recreational facilities (paddling, open areas, etc.)	Health concerns (mosquito breeding grounds)

10.3.2.5 Reduced energy consumption

"*Vegetated roof covers in urban areas offer a variety of benefits, such as extending the life of roofs, reducing energy costs* …." (USEPA, 2000). A reduction in energy costs is related to the reduction in ambient temperature as a consequence of the insulation offered by green roofs. The ability to reduce ambient temperatures has recently been confirmed in a study for the eThekwini Municipality. The study showed that the use of green roofs decreases the air temperatures and insulates the roof (Greenstone, 2010). This insulation effect can reduce energy requirements of entire buildings (ECONorthwest, 2007) while concurrently reducing pollution and improving aesthetics (US Department of Defense, 2010).

A "Guideline for designing green roof habitats" (van Niekerk *et al*., 2011) was developed as part of the Green Roof Pilot Project (GRPP), an initiative of eThekwini Municipality's Environmental Planning and Climate Protection Department. The GRPP was initiated in 2008 with the aim of assessing the effectiveness of green roof habitats in Durban in terms of reducing temperatures and stormwater runoff, both of which are projected to increase as a result of climate change.

10.3.3 SuDS Economic Model

The SuDS Economic Model (SEM) comprises Excel macro-enabled software that was developed to assist in the economic analysis of alternative approaches to stormwater management. The SEM is available as part of the RSA SuDS Guidelines (Armitage *et al*., 2013) and Appendices D-G of the report provide a full description of the operation and functioning of the model.

10.4 Risk assessment

While SuDS may offer a range of valuable ecosystem services it is important to consider the risks of implementing a SuDS system. As noted previously, this is especially important in South Africa where stormwater in both formal and informal areas may be contaminated by sewage. The types of pathogens occurring in urban stormwater will differ from area to area depending on land use, population density, sanitation systems, etc. As part of any scientifically-based risk management system, such focal points of contamination should be investigated. Practitioners should consider the composition of the stormwater in their area, including all chemical and biological pollutants, and ensure that their designs do not unduly increase the risk to public health and safety. In line with conventional stormwater design, a risk assessment based on the hydraulic design should also be undertaken. A further essential characteristic of the design of urban stormwater management systems should be the incorporation of possible points of diversion or other means of temporary interception in the case of outbreaks of waterborne disease (e.g. cholera) so as to limit the spread of disease until such time as the outbreak has been contained.

10.5 Legislation

"*The regulatory backdrop provides a clear responsibility for the control of stormwater, placing this responsibility in the hands of the local authority...*" (Buys & Aldous, 2009). South Africa's municipalities are beginning to develop their own policies to maintain and protect their watercourses along with the expectation that landowners take reasonable steps to treat stormwater. This means that a failure to take 'reasonable means' and thus to prevent pollution of receiving water bodies from stormwater runoff may conceivably result in the landowner being held legally liable. The legislation pertaining to stormwater must be taken into consideration when conducting an economic comparison of stormwater technologies, even if the liability cannot be directly assessed.

10.5.1 SuDS-oriented legislation

A number of national and provincial pieces of legislation point towards the need to manage stormwater in a manner that reduces the amount of pollutants entering receiving water bodies. It is however relatively difficult to set national stormwater policy beyond simply emphasising the need for water quality and quantity management, owing to the wide range of environmental factors in different geographical locations. Taking infiltration as an example – the setting of stormwater quality standards for infiltration is not possible at a national level. This is due to the fact that in certain parts of the country (e.g. in dolomitic areas) infiltration of stormwater could pose a significant threat and should generally not be permitted at all. Additionally, the enforcement of national policies which affect municipal decisions such as land rezoning and development rights can be problematic, as it is difficult for national government to anticipate local issues. There is a need for the development and adoption of local policies and bylaws with respect to SuDS; several Metropolitan municipalities in South Africa have therefore developed, or are currently developing, new stormwater policies as shown in Table 10.6.

Table 10.6: South African SuDS-oriented stormwater legislation

Local Authority	Policy / by-law	Status	Overview
City of Cape Town	Stormwater Management By-Law	Gazetted (PG6300; Provincial Gazette: CoCT, 2005)	The purpose of the by-law, as stated in the opening abstract is to, "*provide for the regulation of stormwater management in the area of the City of Cape Town, and to regulate activities which may have a detrimental effect on the development, operation and maintenance of the stormwater system.*"
	Management of Urban Stormwater Impacts Policy	Adopted (May 2009; CoCT, 2009a)	One of the first policies in RSA to place value on stormwater in the context of the national water crisis and 'climate change'. The following is stated in the preamble; "*Well-managed urban water bodies are valuable resources providing environmental and recreational services which require protection and enhancement. This is particularly important in the context of changing weather patterns and the associated local, national and international strategies targeting sustainability, climate and energy issues.*"
City of Cape Town	Floodplain and River Corridor Management Policy	Adopted (CoCT, 2009b)	The Floodplain and River Corridor Management Policy (May 2009) is not directly associated with stormwater management; but it necessitates the importance of well managed and sustainable watercourses, and places significant value on the use of stormwater runoff (CoCT, 2009b).
City of Johannesburg	Stormwater Management By-laws	(City of Johannesburg (CoJ 2010)	The by-laws aim to manage, control and regulate the quantity, quality, flow and velocity of stormwater runoff from any property in the municipal area.
eThekwini Municipality	Guidelines & policy for the design of stormwater drainage and stormwater management systems.	Current guidelines for stormwater designs submitted to eThekwini Municipality	"*.. stormwater systems designed on the basis that not more than 40% of the area of residential properties would be hardened. As such, any development in such areas in excess of a 40% limitation naturally implies that the developer must be held responsible to manage the excess runoff from such a site for the proportion of hardening in excess of 40%....*"

It is important to note that while some municipalities are moving towards SuDS, and are implementing or drafting by-laws to this effect, a number of other municipalities may still have by-laws in place which are counter to the notion of SuDS, e.g. by-laws which enforce the channelling of runoff from properties to the road.

10.6 SuDS as a component of WSUD

To summarise, this chapter has outlined how Sustainable Drainage Systems (SuDS) may be used to holistically manage urban drainage as a component of Water Sensitive Urban Design (WSUD). Stormwater management in the urban areas of South Africa has focused and continues to predominantly focus on collecting runoff and channelling it to the nearest watercourse. This means that stormwater drainage currently prioritises quantity (flow) management with little or no emphasis on the preservation of the environment, with the result that there have been significant negative impacts on the environment from erosion, siltation and pollution. An alternative approach is to consider stormwater as part of the urban water cycle through the stormwater management component of WSUD known as SuDS – in an attempt to manage surface water drainage systems holistically in line with the ideals of sustainable development. A review of South African legislation – including national policies and guidelines – reveals that whilst very little has been published to directly promote SuDS, the need for such an approach is implicitly suggested.

A brief review has been provided of the South African SuDS Guidelines which have recently been published by the WRC (Armitage *et al.*, 2013). The RSA SuDS Guidelines summarise key material from stormwater management manuals from around the world in such a way as to be relevant to all South African professionals working with stormwater – and not just engineers. The Guidelines were not intended to be a design manual but a way of highlighting potential opportunities for better stormwater management. The Guidelines are available on the WRC website (www.wrc.org.za); and on the South African Water Sensitive Urban Design website (www.wsud.co.za).

11. Sanitation / wastewater minimisation

The primary objective of any sanitation system is to protect and promote human health through the creation of a healthy and clean environment (Graham, 2003). There is a clear correlation between sanitation and health; improved sanitation reduces the risk of gastro-intestinal faecal-oral diseases as well as disease carried by insect vectors (Mara *et al*., 2010). The provision of sanitation is a basic right in South Africa and national policy requires that all citizens have access to a basic level of service (RSA, 2001). There are a range of technical sanitation options available; however it has become clear that selection of these options is heavily dependent on social acceptance. A lack of or inadequate sanitation services can have serious detrimental effects on the environment, the economy and social stability (Tayler *et al.*, 2003). Thus a variety of drivers for sanitation need to be considered in the selection of any sanitation option.

South Africa's urban environments have a diverse range of socioeconomic contexts, each presenting its own challenges with regard to the provision of appropriate sanitation. Sanitation service delivery within the developing urban areas of the country is largely associated with servicing informal settlements. The layout and location of these settlements present a host of technical challenges that need to be carefully considered to ensure that sanitation systems function appropriately. Aside from the technical constraints associated with the provision of sanitation solutions within informal areas, there are several other factors that influence the sustainability of a sanitation system, including cost, social acceptance and institutional accountability (e.g. Taing *et al*., 2013). Although the health objectives of sanitation are critical, the correlation is not always obvious to sanitation users, the result being that consumers desire improved sanitation services for a host of different reasons – such as dignity, privacy, convenience, safety and even prestige (De Bruijne *et al.*, 2007; Tayler *et al.*, 2003) It is therefore vital to recognise that although the health objectives of a sanitation system need to be achieved, unless the secondary objectives are incorporated there will be little community buy in. A consequence of this is that the system is very likely to fail and no health improvements will be realised (Graham, 2003). Economic considerations such as affordability are also important to ensure that the system can be operated and maintained to ensure a sufficient level of service. Once again it is vital that both the consumers and service providers clearly understand their roles and responsibilities with regard to the operation and maintenance of these systems.

Although there are significant challenges associated with the provision of appropriate sanitation within informal areas, a large proportion of urban areas are serviced by conventional waterborne sewage reticulation networks. Given the large quantities of wastewater generated by domestic, commercial and industrial processes, wastewater has the potential to become a valuable water resource. Wastewater can be re-used at a variety of scales ranging from a decentralised household level to large-scale centralised re-use schemes from wastewater treatment works. Treatment of wastewater has however potentially big economic implications which are dependent on the level of treatment required; for example, treating water to potable standards is expensive and requires large amounts of energy. One of the most critical concepts promoted by the WSUD paradigm is thus the ‘fit for purpose’ approach. There are many water use activities that could substitute treated wastewater for potable water. Activities such as garden watering, toilet flushing, and building cooling do not require potable water and a lower quality wastewater could provide an ideal substitute thus reducing the demand for high quality potable water. In order to promote the more efficient use of water resources, it is important to capitalise on the potential use of wastewater as an alternative water source, provided the health and environmental aspects can be satisfactorily dealt with. From a sustainability perspective, wastewater treatment also holds promising potential in terms of the extraction of alternative energy sources such as methane and hydrogen; this highlights the need to take the principles of sustainability beyond the urban water paradigm and into the broader context of developing sustainable cities.

Managing sanitation in an urban environment is a difficult task and there are many facets to the challenge of achieving the WSUD objective of transitioning to water sensitive settlements. For the purposes of these guidelines the sanitation challenge from a WSUD perspective will be split into four main components:

- **Appropriate sanitation –** which covers issues related to the provision of sanitation and the challenges associated with providing alternative sanitation to the urban poor.
- **Sanitation options** – the range of sanitation options that could be used in place of conventional waterborne sewerage.
- **Wastewater as a resource –** which highlights the potential for wastewater re-use as a substitute for potable water.
- **Wastewater and ecological sustainability –** which highlights the link between effective wastewater management and healthy ecosystems, as well as the need to integrate sustainable water management with other sectors involved in the urban sustainability challenge.

11.1 Appropriate sanitation

South Africa’s cities have diverse socio-economic profiles and given the urgent service delivery needs, the issue of appropriate sanitation has become an important consideration given the difficult physical constraints limiting the feasibility of full waterborne sanitation systems within areas such as informal settlements. Appropriate sanitation can be defined as “*That which meets the needs of people in the best possible way in relation to the resources available and other aspects of the local situation*” (Pickford, 1995:4). Many sanitation systems if operated correctly under the right conditions fulfil the required health objectives; however this does not guarantee that they are sustainable. Graham (2003) notes that the sustainability of any sanitation system relies on three factors: social acceptance, technical design and affordability.

11.1.1 Social acceptance

The sustainability of any sanitation system is heavily dependent on community acceptance. The systems need to be sensitive to cultural norms and practices and should meet the expectations of the community if they are to be operated and maintained correctly. The issue of expectations is particularly sensitive in South Africa; past inequalities coupled with political promises to address these issues have placed significant pressure on service providers to provide full waterborne sanitation systems. The slightest deviation from what is conventionally provided for middle-income households can have unfortunate consequences. The eThekwini pilot shallow sewer project is an example of this. Whilst shallow sewers (sometimes known as 'simplified sewers' as these sewers are designed to somewhat 'relaxed' design standards – and frequently maintained by the residents through a social compact in Brazil, i.e. 'condominial sewers') – were shown to be a viable alternative waterborne sanitation system in low-income, dense settlements from a technical perspective; community acceptance and ownership issues were sufficient to derail the project (Eslick & Harrison, 2004). Similarly, a recent attempt by eThekwini Municipality to introduce treated sewage effluent into the potable water system also met with strong resistance from members of the public. The provision of sanitation systems will need to involve extensive communication with the consumers to ensure community support for the proposed sanitation option.

11.1.2 Technical design

Aside from achieving the objectives of improved health, sanitation systems need to be robust. Sanitation systems are often subjected to intensive use, particularly in communal or public facilities, and are very often open to misuse. These systems need to be easy to construct, and simple to operate and maintain; this is because they are more likely to be sustainable when users assume responsibility for maintenance from the service provider. In particular, the selection of an appropriate sanitation option needs to take into consideration the fact that the system should have sufficient capacity to cater for its intended use. This is of particular concern from a human health and environmental perspective when on-site sanitation options are selected.

11.1.3 Affordability

Affordability of sanitation options relates both to the initial capital costs, as well as the operation and maintenance costs to sustain the system. This is further complicated by the fact that it is not just about identifying who pays for these systems, but also who pays for the various components (Graham, 2003). The challenge of cost evaluations is particularly difficult for alternative sanitation options where external and internal costs differ from conventional sanitation systems. There needs to be a clear basis for evaluating the costs of alternative sanitation approaches against conventional systems.

11.2 Sanitation options

There are a wide range of sanitation options that could be used in place of conventional waterborne sewerage to allow for the integrated management and beneficial re-use of wastewater, as part of WSUD. It is beyond the scope of these guidelines to describe the various options; however DWAF (2002); Tilley *et al*. (2008) and Stenström *et al*. (2011) provide a comprehensive review of the various sanitation options available and some of the challenges associated with the implementation of these systems in RSA. Figure 11.1 illustrates examples of some of the various sanitation options available; and the advantages and disadvantages of these systems are discussed in Table 11.1 and Table 11.2.

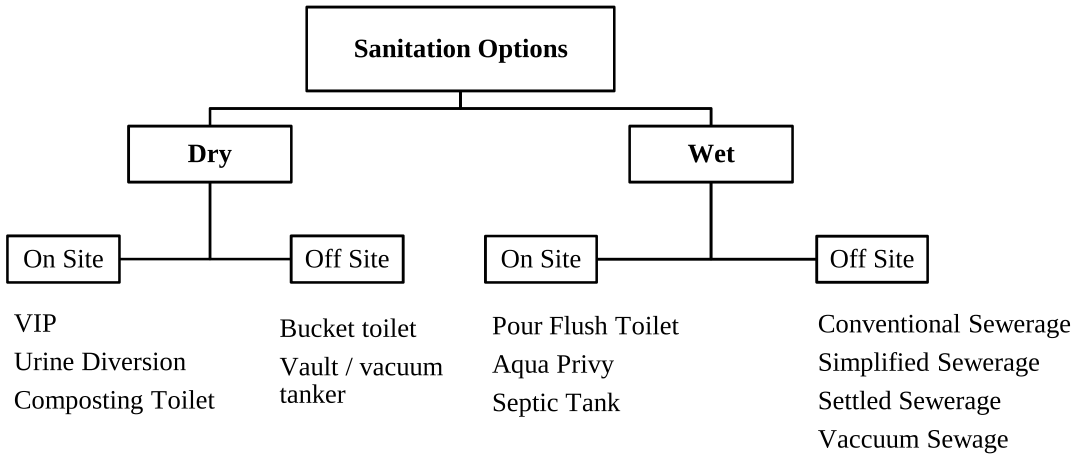


Figure 11.1: **Wet and dry sanitation options**

Table 11.1: Wet sanitation options

Wet option	How it works	Advantages	Disadvantages
Pour flush toilets and conservancy tanks	• Usually no cisterns for water storage. • Water is poured in manually to clean the bowl and flush contents into conservancy tank. • A water seal can be maintained in the pour flush bowl preventing odours from the conservancy tank from rising. • Considered a low-flow sanitation system requiring typically 1-3ℓ per flush (CSIR, 2001; Graham, 2003).	• Uses less water than conventional sewerage. • Can be used in areas without sewerage. • Potential for upgrade to settled sewerage. • Can be used in high-density areas. • Can be fitted with a low-flush or sullage-flush cistern.	• Cumbersome to carry water from taps to toilet. • More frequent emptying required than dry systems. • May require vacuum tankers to empty tanks. • Easily blocked if bulky anal cleansing material is used.

Table 11.1 (cont.): Wet sanitation options

Wet option	How it works	Advantages	Disadvantages
Aquaprivy	• Watertight tank located directly under the pedestal / squatting plate. Vertical drop-pipe extends approximately 100 mm below the liquid level in the tank to form a crude water seal. • Solids sink to the bottom of the tank where they are anaerobically digested.	• Relatively inexpensive system. • Can be fitted with a low-flush or sullage-flush cistern.	• Where water is scarce the seal is often broken and flies, mosquitoes and odours become a problem. • Once the tank is full it has to be desludged.
Septic tank and soakaway	• A watertight tank that obtains waste from the pedestal or squat pan through a standard volume or low-flush cistern. • Solids settle to the bottom of the tank where they are anaerobically digested. Liquid and suspended solids fraction forms a middle layer and liquid is drained off to a soakaway.	• Acts as a primary treatment process. • Greywater can be added to the system. • The most appropriate system for upgrade to a settled sewerage system.	• Tank needs to be desludged every 1-5 years. • Foreign objects may cause malfunctioning of the system. • Relatively expensive and require open space for wastewater percolation.
Settled sewerage	• Similar to conventional sewerage with an interceptor tank added to each connection point to the sewer line to remove 'settleable' solids, allowing for smaller diameter pipes and more flexible layouts • Usually considered as a service upgrade to areas with existing septic tanks	• Depending on the layout (e.g. if septic tanks already exist), it can be considerably cheaper to install than conventional sewerage. • Removes the majority of solids before the effluent enters pipe network; thus less potential for blockage. • More flexibility in pipe layout – can even tolerate short lengths of adverse (upward) slopes.	• The interceptor tanks are expensive to construct if no existing septic tanks are available for conversion. • High operational cost associated with emptying of interceptor tanks.
Simplified sewerage	• Operates on same principles of gravity as conventional sewerage, but with 'relaxed' design standards, e.g. smaller diameter pipes, shallower gradients, and simplified inspection chambers instead of manholes. • Generally only suitable for areas that are not subject to vehicle loading (has to be specially protected if vehicles expected. • Can be constructed by the beneficiaries with the assistance of the local authority.	• Considerably cheaper than conventional gravity sewer systems. • Increased focus on community engagement throughout design, planning and operation and maintenance. • Additional savings to the local authority if constructed and maintained by the beneficiaries (condominiums).	• Requires more responsibility from communities to maintain than the conventional gravity system if condominial layout is used.

Table 11.1 (cont.): Wet sanitation options

Wet option	How it works	Advantages	Disadvantages
Conventional sewerage	• Requires on-site water supply source as well as either a septic tank or sewered connection. • Waterborne system that uses gravity to convey wastewater through a reticulation network to a treatment plant. • Typically uses 6-9ℓ of water per flush, but lower volume flush mechanisms can reduce the water demand.	• Hygienic and free of flies and odours if properly operated and maintained. • High level of user convenience. • Can be used in high density areas. • Familiar system for technicians, plumbers, etc.	• Expensive to install, operate and maintain. • Requires high level of water supply service. • Efficient institutional organisation needed. • Easily blocked if bulky anal cleansing material is used.
Vacuum sewerage	• Uses differential air pressure to propel sewage through the main sewer network (USEPA, 1991). • Three major components: the service (sump, vacuum valve, sensor unit), the collection mains, and a centrally located vacuum station (which houses the vacuum pumps, vacuum vessels and discharge pumps) (USEPA, 1991).	• Due to reliance on pressurised system smaller pipes and more flexible pipe layouts can be used. • Sewage can be propelled up to 5 m uphill with requiring additional pumping. • Manholes not needed. • Leaks are immediately identified by pressure reduction measured at vacuum station. • Fewer pump stations needed than with conventional systems usually (depends on local conditions).	• Expensive to install, operate and maintain. • Requires specialised equipment to locate leaks in vacuum system. • Difficult to procure expensive replacement parts in South Africa. • Sensor valves are easily damaged by sharp solids.

Table 11.2: Dry sanitation options

Dry option	How it works	Advantages	Disadvantages
Ventilated Improved Pit (VIP) latrine and other variations	• More hygienic pit latrine with ventilation to toilet unit through dark-coloured vent pipe that heats up thus creating convection current to assist with air flow out of vent. • Includes a firm area for either sitting or squatting depending on whether or not a pedestal or squat pan is used. • Solids accumulate in the pit and decompose anaerobically; liquid percolates into the ground if the pit is unlined.	• Waterless system (applies to all). • Locally available materials used for construction. • Components can be manufactured commercially and erected on a number of plots within a short space of time. • Ventilation reduces smell and flies.	• The system cannot ordinarily be installed inside a house. • Requires a pit-emptying service in high-density areas. • Not recommended for very dense areas and where ground conditions are unsuitable (Kirke, 1984 in Graham, 2003).

Table 11.2 (cont.): Dry sanitation options

Dry option	How it works	Advantages	Disadvantages
Urine Diversion Dehydration Toilet (UDDT)	• Units which separate urine from faeces by means of a specially designed pedestal; the front of the pan has dished cover with small hole which diverts urine into a soakaway or storage container while the faeces drop into a vault below where they are stored and dehydrated for later removal. • The installation of two vaults in parallel allows for alternating usage; when one vault is full the toilet can be moved to the other vault while the contents of the full vault dry and decompose. • Ash, wood shavings or other dry organic matter needs to be added to help absorb moisture and minimise odours.	• Hygienic if maintained properly. • Re-use of urine and faeces is facilitated. • Building materials can be acquired locally or commercially made. • Installation can be performed by unskilled workers.	• Operation needs adherence to a number of stringent requirements for high-level commitment from owners. Not suitable for dealing with greywater. • Exposure to faecal matter during the turning over and removal of the contents of the vault. • High capital cost. • Difficult to produce usable compost.
Composting toilet	• Similar to pit toilets, where excreta are stored in containers below the pedestal / squat hole. • Conditions are created that stimulate aerobic breakdown of waste, so that the degraded material can be used as fertilizer and soil conditioner.	• Most long-term sustainable solution because no environmental damage is caused, the nutrient cycle is completed and precious resources are not wasted.	• System is fairly high maintenance and users have to know what can and cannot be put into the toilets. • Composting toilets require the manual handling of the decomposed material.

11.3 Wastewater as a resource

The management of the wastewater stream forms a major component of the objectives of WSUD. The Queensland Department of Infrastructure and Planning highlights the objectives of WSUD with respect to wastewater management as follows (QDIP, 2009:1):

- Protecting the quality of surface and groundwater to maintain and enhance aquatic ecosystems and enable re-use opportunities.
- Promoting more efficient use of water by reducing the demand for potable water and encouraging use of alternative water supplies.
- Minimising the generation of wastewater and ensuring it is treated to a sufficient standard to enable the effluent to be re-used and/or released into receiving waters.

11.3.1 Wastewater re-use

South Africa's towns and cities produce large quantities of wastewater on a daily basis; most of this is passed through wastewater treatment works and is discharged into receiving waterways. The exploitation of this valuable water source could significantly reduce potable water demand within urban areas as well as the quantities of wastewater generated (Landcom, 2004b). The level of treatment required before re-use is dependent on the quality of the wastewater recovered as well as its intended end use. Wastewater can be split into two broad components, blackwater and greywater. Blackwater refers to water with high concentrations of faecal matter and urine, and as a result is highly contaminated and difficult to treat. Greywater refers to wastewater generated from all other domestic processes and contains far less organic pollution. There are a variety of strategies that can be used to recover wastewater at different scales for a range of applications. Three are of particular significance to this chapter: greywater re-use, wastewater recycling and sewer mining.

Without treatment, greywater is not fit for human consumption and care should be taken to limit human contact. Even greater care needs to be taken with blackwater which is highly contaminated and requires intensive treatment before re-use (City of Melbourne, 2009). From a 'fit for purpose' perspective, greywater is most appropriate for activities such as toilet flushing and garden watering where human contact is limited. Using greywater for in-house domestic consumption requires additional infrastructure (such as pumps, tanks and on-site disposal systems) as well as the active participation of residents to ensure the system works effectively (Landcom, 2004b). Blackwater can be re-used by treating the water at a centralised sewage treatment plant and redistributing the treated effluent through a 'third pipe' system.

Alternatively blackwater can be re-used through the practice of sewer mining. Sewer mining involves the extraction of blackwater from a sewage system (usually before the sewage treatment plant) and treating it for re-use (City of Melbourne, 2009). These small treatment plants do have a large energy footprint, however they provide a space efficient, and decentralised system with a relatively consistent water supply.

11.3.2 Wastewater minimisation

Wastewater minimisation helps to reduce sewage conveyance volumes, treatment requirements, sewer overflows and the discharge of nutrients into receiving waterways (Water by Design, 2009). The following methods can be adopted to minimise wastewater production (*ibid*):

- Reduce wet weather flows by minimising stormwater ingress and eliminating accidental or illegal cross connections between sewage and stormwater networks.
- Reduce wastewater discharge from housing developments through demand management techniques and maximising wastewater re-use opportunities.

11.4 Wastewater and ecological sustainability

11.4.1 Water quality and ecological protection

The objective of ecologically sustainable development is at the heart of the WSUD paradigm. Effective management of wastewater is critical to promoting healthy urban waterways and sustaining natural ecosystems. In South Africa wastewater treatment plants (WWTPs) are generally used in urban areas to treat effluent before discharge into receiving waterways. Treated wastewater can often have a detrimental impact on the water quality of receiving waterways, particularly if the treatment quality is substandard. The environmental impacts associated with wastewater vary depending on the level of treatment before discharge; however even low concentrations of chemical constituents in wastewater can still lead to significant alterations in the nutrient balances in a water body (Muga & Mihelcic, 2008).

In South Africa many WWTPs do not conform to the desired quality standards – as illustrated in Figure 11.2 which summarises the performance of South Africa's 821 WWTPs during 2010 / 2011 (note – this figure is based on number of treatment works and not on volumes treated).

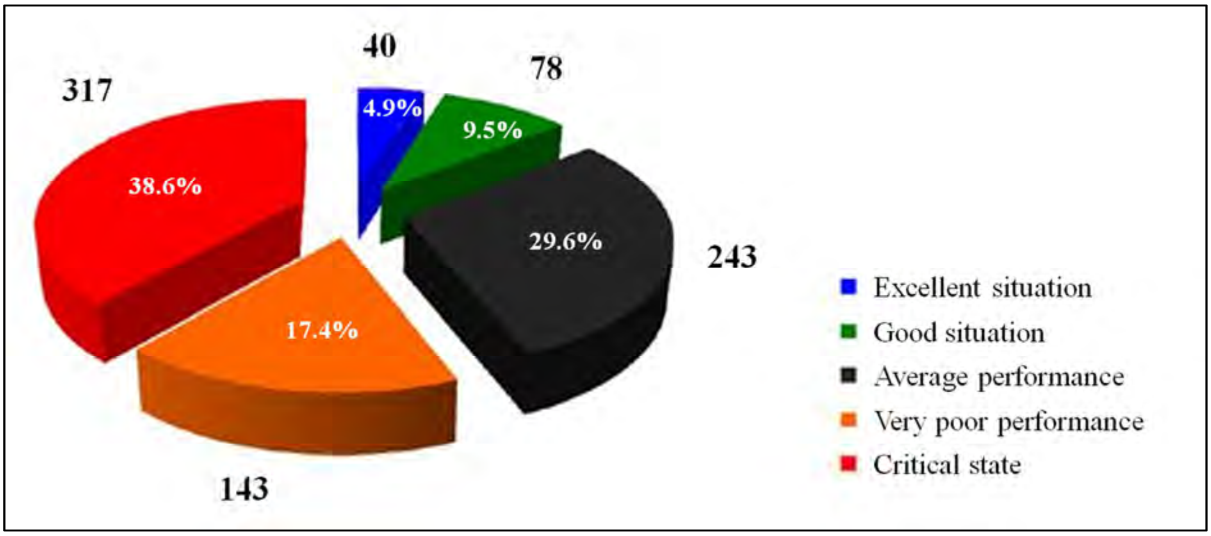


Figure 11.2: Summary of wastewater treatment plant performance in RSA (DWA, 2011)

Nearly 40% of South Africa's WWTPs are deemed to be in a 'critical' condition; i.e. needing urgent intervention for all aspects of the wastewater services business (DWA, 2011). This has major implications for natural waterway health downstream of these sites. In order to achieve the WSUD objectives of protecting the quality of surface and groundwater the treatment of wastewater will need to undergo significant improvement in South Africa's urban areas. One of the ways in which wastewater treatment works can improve their performance is through compliance with the Department of Water Affairs' Green Drop certification program. The Green drop certification process is an incentive-based regulation program that aims to improve the level of wastewater management in South Africa (DWA, 2011). The process measures and compares the results of the performance of water treatment works, and subsequently acknowledges the service provider upon evidence of their excellence (or failures) according to the minimum standards and requirements that have been defined (*ibid*). Compliance with the minimum requirements of the Green Drop process will have a significant impact on the quality of treated effluent discharged into South Africa's waterways and could promote a shift to more sustainable aquatic ecosystems within the urban setting.

11.5 Sanitation as a component of WSUD

Sanitation is a basic right in South Africa and the provision of appropriate sanitation to all citizens is a priority service delivery issue. There are many facets to the sanitation challenge aside from the technical challenges however; there are also significant socio-political, economic and environmental issues. A transition to sustainable sanitation systems will need to balance South Africa's social development objectives with the environmental imperatives of ecologically sustainable development.

There are particular challenges to implementing WSUD in South Africa related mainly to a different social and economic reality with higher levels of poverty and also inequality than in countries such as Australia, where the concept of WSUD originated. The question of how to incorporate the sanitation component in the context of low-income urban areas in South Africa is still a work in progress. It is important to note that sanitation in the context of WSUD should not be conflated with dry sanitation options alone – particularly since the fraction of water used directly by lower-income South Africans for domestic purposes is significantly lower than in higher income brackets (Van Zyl *et al*., 2008).

One of the features of a more sustainable sanitation system is that it should optimise the use of resources such as nutrients, water and energy. This would include, but not be limited to, the adoption of alternative sanitation technologies such as dual reticulation systems, urine diversion, or composting. Another key feature is the potential for greater inclusion of low-income urban areas into a more holistically designed and managed urban water cycle – provided there is a clear understanding of responsibilities for operation and maintenance, as well as community expectations regarding the provision of sanitation. Greater inclusivity and secondary benefits from sanitation could be achieved through not only well-designed infrastructure, but also through the city-wide social and institutional processes of negotiation, participatory planning / visioning, consensus building, etc. that would be required to implement WSUD on a large scale.

Wastewater is a major component of the urban water cycle. There is significant potential to exploit this resource on a 'fit for purpose' basis. Not all water use activities require potable water; treated wastewater can provide a very useful and economically feasible alternative. Wastewater re-use can be applied at a range of scales and there are several strategies, both centralised and decentralised, that could be adopted to take advantage of this resource. It should be borne in mind, however, that untreated wastewater can adversely impact natural environments and the proper treatment of wastewater before discharge is a critical component of sustainable wastewater management strategies. Many wastewater treatment works in South Africa do not comply with the minimum water quality standards and the management of these facilities will need to undergo significant improvement if the transition to sustainable wastewater management is to be realised.

12. Groundwater management

In the context of a Water Sensitive Settlement, all forms of water in the urban environment have a resource value, *viz.* stormwater, wastewater, greywater, potable water and groundwater (Whelans *et al.,* 1994; Wong, 2006; Water by Design, 2009; JSCWSC, 2009; QDIP, 2009). Of these, groundwater arguably receives the least consideration because it is a ‘hidden’ part of the resource and as a result is often poorly protected (Foster *et al*., 1998). Yet, groundwater is a valuable water resource (particularly in terms of its storage value) that is closely connected to surface water resources and plays an important role in sustaining ecosystem goods and services (Bergkamp & Cross, 2006).

12.1 Urban groundwater and WSUD

Many of the world’s largest cities, such as Mexico City, Shanghai, Jakarta, Cairo, London and Beijing rely on groundwater for more than 25% of their water supply (Wolf *et al*., 2006). South Africa on the other hand, depends largely on surface water resources, with less than 15% of the total water supply estimated to be groundwater (Sililo *et al*., 2001; DWA, 2010b; DWA, 2010c). However, at least 80% of South Africa’s available surface water resources have already been allocated (DWA, 2010b), and many parts of the country are fast approaching the point at which all of the easily accessible freshwater resources are fully utilised (DWA, 2013). Given the strain on available surface water resources, groundwater may hold the potential to meet some of South Africa’s growing water requirements (DWA, 2010b; DWA, 2012).

A number of urban areas in South Africa rely on groundwater to assist in meeting their demands for water. Pretoria and Atlantis are good examples of urban areas in South Africa that have made use of groundwater. In Pretoria much of the central parts of the city are supplied by local springs and boreholes (Dippenaar, 2013a) and in Atlantis, Cape Town most of the water supply is from groundwater resources. The groundwater in Atlantis is also recharged with stormwater and treated wastewater (DWAF, 2007; DWA, 2010a). However, urban groundwater management in the rest of South Africa has largely been ignored, and suffers from a general lack of investment (Tuinhof *et al*., 2011). In many instances urban groundwater management is not politically attractive as it may only yield benefits in the long term (Foster *et al*., 1998). Foster *et al*. (1998) describe groundwater as “*out of public sight, and therefore out of political mind*”; however Hancock (2000) suggests that groundwater should be viewed as a valuable resource. This highlights a central problem for sustainable groundwater governance, i.e. that groundwater lacks public, professional and governmental awareness (FAO, 2003).

12.2 Positioning groundwater in WSUD

In a review of groundwater in the Australian city of Melbourne, Mudd *et al.* (2004) link groundwater to WSUD through infrastructure, wetlands and Managed Aquifer Recharge (MAR). Although these groundwater links were specific to Melbourne, general principles relating to groundwater and WSUD can be deduced, *viz*. groundwater is impacted by water-related infrastructure; it has an important ecological role through interaction with surface water; and it is a potential means of water storage.

12.2.1 Groundwater and infrastructure

Urban infrastructure, whether it is for stormwater, wastewater or water supply, is closely linked to groundwater, and impacts on the quantity and quality of groundwater. For example, urban groundwater functions as both a source of water and a receptor of urban drainage (Hancock, 2000; Morris *et al*., 2003). Over-abstraction of groundwater can cause saline intrusions and land subsidence (Morris *et al*., 2003), while excessive groundwater recharge can result in structural damage to buildings and may cause flooding to underground basements and parking lots (Lerner, 2002). Groundwater recharge can occur as a result of sewer and water supply leakages, as well as from the over-watering of parks and recreational areas, which can cause increases in groundwater levels (Lerner, 1990; Lerner, 2002; Wolf *et al*., 2006). Wastewater from on-site sanitation, leakages from sewage networks or municipal and industrial wastewater can also raise water tables and can furthermore be detrimental to urban groundwater quality (Lerner, 2002; Morris *et al*., 2003; Mudd *et al.*, 2004; Wolf *et al*., 2006). WSUD requires a sound understanding of the relationship between groundwater and urban infrastructure to ensure the proper groundwater quantity and quality is achieved and maintained. It is important therefore, that a hydro-geologist is consulted before undertaking a WSUD project that impacts on groundwater resources. The interactions between groundwater and WSUD have been summarised as depicted in Figure 12.1 and Table 12.1.

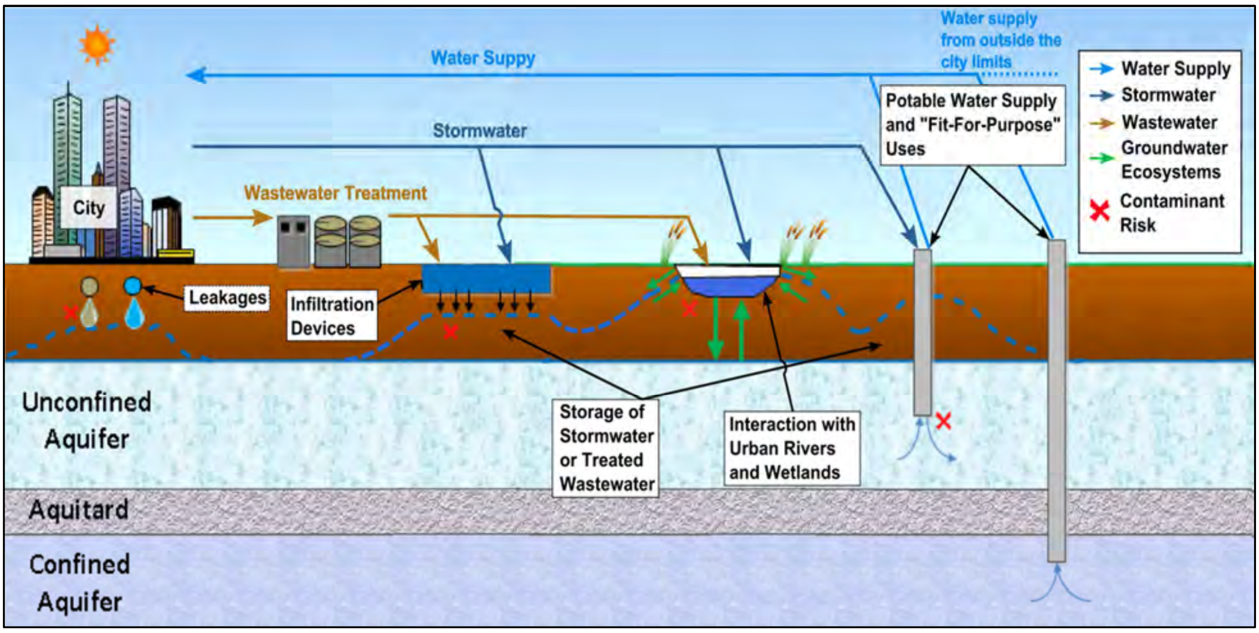


Figure 12.1: Various WSUD-groundwater interactions, risks and management responses

Figure 12.1 addresses the concept of the risks to groundwater in terms of urban infrastructure, ecosystems and storage and relates these to the WSUD approach (techniques and technology), as follows:

- There are three main sources of water that interact with groundwater in terms of WSUD, *viz*. potable water, stormwater and wastewater.
- Groundwater is a source of water supply and it can be used as a form of water storage.
- Stormwater or treated wastewater can be stored using infiltration devices that allow water to infiltrate from the surface to groundwater or by the subsurface injection of water into an aquifer for storage and later use.
- The quality of water that is infiltrated or injected into an aquifer is important. The quality of stormwater varies and may contain contaminants such as heavy metals, nutrients, salts and microorganisms.
- Wastewater may be treated to a reasonably high standard before infiltration or subsurface injection which would reduce the threat to aquifer health.
- Infiltration devices are able to remove a number of potentially hazardous contaminants that find their way into groundwater. The design of these devices will need to consider the risks of polluting the groundwater. These devices will likely require regular maintenance to prevent clogging.
- Many ecosystems are dependent on groundwater contributions or may contribute to groundwater recharge and must be protected from contamination.
- Leakages from urban infrastructure are a concern as this can result in uncontrolled increases in water level and groundwater contamination.
- The areas that are at risk of contamination are marked with an ‘X’ in Figure 12.1. These include leakages from sewerage networks, the infiltration or subsurface injection of stormwater or wastewater, as well as the potential for polluted surface water to contaminate groundwater, and *vice versa*.

Table 12.1 addresses the three main areas of groundwater interaction with WSUD, the associated risks in these areas, and the possible management responses required by WSUD to ensure its successful application.

12.2.2 Groundwater and surface water interactions

Groundwater contributes to stream flow generation in the form of base-flow, which is the contribution of groundwater discharge to stream-flow. Furthermore, stream-flow contributes to the recharge of groundwater (Todd & Mays, 2005). Groundwater plays a crucial role in the health of ecosystems in rivers and wetlands, thereby offering valuable ecosystem goods and services, such as water supply, flow regulation, contaminant removal and food, as well as recreation and aesthetic value (Weight, 2008). Mudd *et al*. (2004) suggest that there is a lack of understanding of the interactions between surface water and groundwater in a number of WSUD technologies.

Table 12.1: Groundwater management: interactions, risks and responses

Groundwater interactions	Groundwater risks	Groundwater management response
Infrastructure	• Pipe leakage – excessive recharge. • Pipe leakage – groundwater contamination. • Groundwater ingress into underground infrastructure. • Contamination from urban land uses.	• Prevent leakages from underground water pipelines (potable, storm and wastewater). • Urban land use planning. • Installation of monitoring systems.
Groundwater dependent / related ecosystems	• Polluted surface water ecosystems contaminating groundwater. • Polluted groundwater contaminating surface water ecosystems. • Loss of ecosystem goods and services.	• Prevent contamination of ground and surface water. • Protect groundwater related ecosystem services. • Groundwater rehabilitation. • Monitoring.
Groundwater for storage	• Risk of contamination (infiltration devices, ASR / ASTR). • Excessive increases in groundwater levels. • Compromised soil and aquifer structure.	• Careful planning, testing, design and assessment by suitably qualified personnel. • On-going monitoring. • Development of management plans.

12.2.3 Groundwater for storage

The most established role of groundwater within WSUD is in stormwater management, where recharge of stormwater to groundwater provides a means of treatment, as well as storage (Water by Design, 2009; Wong *et al*., 2013). In simple terms, rainwater either leaves the land surface as runoff, or it infiltrates into the soil. Once infiltrated, water can move vertically until it recharges the groundwater, or it can flow laterally within the vadose (unsaturated) zone as interflow (Dippenaar, 2013b). It should be noted that the soil moisture occurring within the vadose zone may not be readily available for abstraction, but it can result in replenishment of groundwater (through the process of recharge – here defined as that process whereby water infiltrates through the vadose zone, eventually reaching the groundwater surface and adding water to the aquifer, occurring as the net gain from precipitation or runoff) and is available for use by plants (*ibid*). Many of the SuDS techniques that interact / impact on groundwater can be directly or indirectly linked to various forms of Managed Aquifer Recharge (MAR); for example: aquifer storage and recovery (ASR), aquifer storage transfer and recovery (ASTR), infiltration ponds, as well as rainfall harvesting techniques (Dillon, 2005) – see figure 12.2.

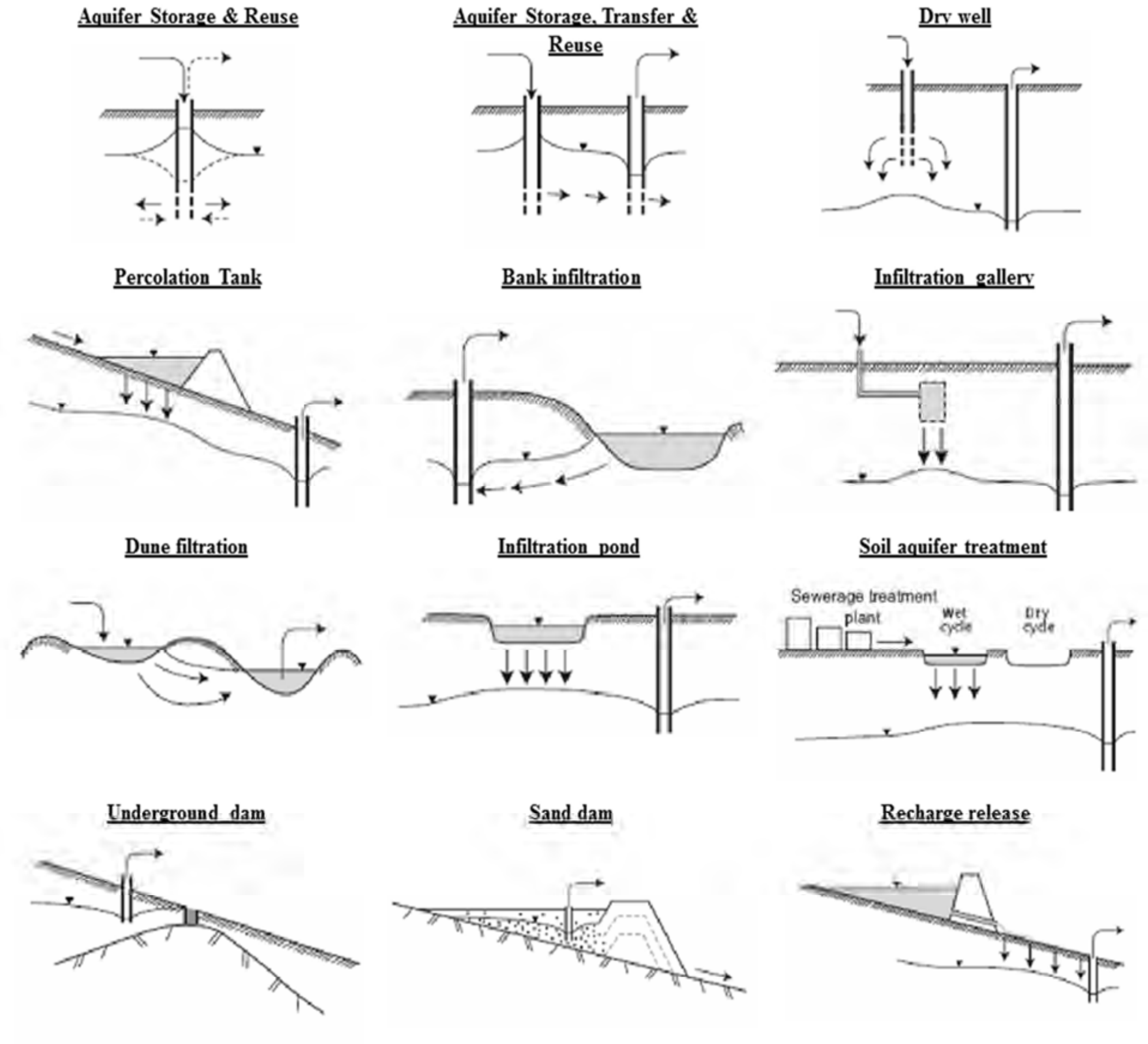


Figure 12.2: Types of Managed Aquifer Recharge (NRMMC *et al.*, 2009)

MAR fulfils a number of WSUD objectives, such as stormwater management, stormwater / wastewater re-use, as well as reducing demand for potable water by providing alternative sources of water that can be used for a number of ‘fit for purpose’ applications. MAR techniques promote aquifer recharge via infiltration or direct recharge, with stormwater, rainwater or treated wastewater.

12.3 Impacts of stormwater management and MAR on groundwater

12.3.1 Stormwater management

WSUD promotes local or source-control devices for stormwater management, which involve managing rainfall where it falls by enhancing infiltration and evapotranspiration (Coombes *et al*., 1999; Ellis, 2000; Wong & Brown, 2008; Wong *et al*., 2013). Stormwater infiltration systems such as rain gardens, infiltration trenches and infiltration basins encourage infiltration and recharge to pre-urban levels (Dierkes *et al.*, 2002), compensate for soil water deficits, increase baseflows, and reduce stormwater volume and peak discharge of storm events, as well as reduce the stress on current stormwater systems (Alfakih *et al.*, 1999; Ellis, 2000; Water by Design, 2009). However, there are also a number of risks associated with the infiltration of stormwater – both in the saturated and (potentially in the) unsaturated zones. These include groundwater pollution (Alfakih *et al.*, 1999; Pitt *et al.*, 1999; Clark & Pitt, 2007; Weiss *et al.*, 2008), increasing groundwater temperature (Foulquier *et al.*, 2009), soil collapse / land subsidence, increases in local water table levels and the altering of natural groundwater flows (Ellis, 2000; Vázquez-Suñé *et al.*, 2005). It is clear therefore that stormwater infiltration has a number of management benefits but there a variety of risks associated with the infiltration of stormwater and the need to be addressed in the WSUD planning process.

The presence of high concentrations of nutrients such as phosphorous and nitrogen in urban stormwater can induce algal blooms and eutrophication in receiving water bodies (Weiss *et al.*, 2008). Sources of nutrients include *inter alia* animal and plant material and fertilisers. The presence of nutrients in groundwater is not always as a result of anthropogenic impacts, but can be associated with the natural soil and geological conditions (Pitt *et al.*, 1999). Nutrients can be removed during infiltration, through precipitation or chemical adsorption onto the surfaces of soil particles through chemical reactions with iron, calcium or aluminium; however the effectiveness of nutrient removal is inconsistent (Weiss *et al.*, 2008). Nitrogen contamination of groundwater is more common than phosphorous (Pitt *et al*., 1999, Burton & Pitt, 2002). The potential for nitrate leaching from an infiltration device is high due to the elevated rates of infiltration and the high solubility of nitrates, making it highly mobile through the soil profile (Burton & Pitt, 2002). Significant nitrate leaching is known to occur during cooler, wet seasons as de-nitrification and plant uptake are slowed due to these cooler conditions. The risk of nitrate contamination of groundwater from stormwater is generally low to moderate due to the typically low concentrations of nitrate in urban stormwater runoff (Pitt *et al.*, 1999; Burton & Pitt, 2002).

Heavy metals such as chromium, copper, lead, nickel and zinc are often present in stormwater – emanating from vehicles and industrial processes (Barraud *et al.*, 1999; Pitt *et al.*, 1999; Dechesne *et al.*, 2004; Weiss *et al*., 2008). Fortunately, most of these metals are in fine particulate form which adheres to sediments that may be readily removed by sedimentation (Burton & Pitt, 2002; Weiss *et al.*, 2008). In sandy or loamy soil, copper, iron and zinc have been known to show higher mobility and nickel and zinc have shown a high potential to contaminate groundwater if subsurface injection is used (Burton & Pitt, 2002). In general, the concentration of heavy metals decreases with depth in an infiltration basin (Mikkelsen *et al*., 1997; Barraud *et al.*, 1999; Datry *et al.*, 2004; Birch *et al.*, 2005). Dechesne *et al.* (2004) suggest that soils with basic pH conditions improve the retention of heavy metals, and Burton & Pitt (2002) suggest that infiltration devices should be kept moist as the drying of the soil allows the adsorption bonds between the sediment and the metals to be weakened therefore allowing further percolation of heavy metals.

Organic compounds can also be found in stormwater. Organic compounds may originate from natural sources, such as decaying animal and plant matter or from anthropogenic sources, such as petroleum hydrocarbons, tyre residue and exhaust emissions from vehicles (Pitt *et al*. 1999). Phthalate esters and phenolic compounds are the most common organic compounds to be found in groundwater, but benzene, chloroform, methylene chloride, trichloroethylene, tetrachloroethylene, toluene and xylene can also be present. Polycyclic aromatic hydrocarbons (PAHs), such as benzo(a)anthracene, chrysene, anthracene and benzo(b)fluoroanthenene have also been detected in groundwater near industrial areas (Burton & Pitt, 2002). Organic compounds are generally removed from water in the soil profile in three ways: volatilisation, sorption or degradation. Volatilisation reduces the concentrations of the more volatile compounds, but this agency becomes less effective with increasing soil moisture. Sorption onto soil organic matter limits the mobility of less soluble compounds, however it does not remove them and furthermore re-solubilisation of organic compounds may occur during wet periods leading to groundwater contamination. Many organic compounds can be removed through microbial degradation; however this is a function of temperature, pH, and moisture content, as well as the ion-exchange capacity of the soil. The use of surface infiltration methods should reduce the concentrations of organic compounds; however pre-treatment is recommended (Barraud *et al*., 1999; Pitt *et al*. 1999; Weiss *et al.*, 2008). Ellis (2000) suggests that stormwater containing high concentrations of organic compounds should not be directly discharged into groundwater due to the compounds' increased mobility under saturated conditions.

Pesticides that are used to control insects and plants may also be found in stormwater and can contaminate groundwater. The risk of pesticide contamination depends on the concentration of pesticides in stormwater and the mobility of the specific pesticide. Most pesticides decompose in soil and water over time, but this can take days or even years. Surface infiltration with pre-treatment could substantially reduce the risk of groundwater contamination; however subsurface injection or infiltration of stormwater with high levels of pesticide should be avoided (Weiss *et al.*, 2008; Burton & Pitt, 2002).

Pathogens present in stormwater have the potential to contaminate groundwater – with stormwater acting as the 'carrier' for distributing disease. Viruses and bacteria are of concern as they can occur in high concentrations in urban stormwater and pass through the soil relatively easily (Weiss *et al.*, 2008). Pathogens can be removed from soil through straining at the soil surface or adsorption to soil particles. The presence and survival time of pathogen is a function of a number of factors such as pathogen type, recharge water source, temperature, redox state and oxygen concentrations, the activity of indigenous groundwater microorganisms and aquifer geochemistry (NRMMC, 2009). However, viruses and bacteria can have lengthy survival times in soil of up to five years (Burton & Pitt, 2002), and the eggs of intestinal nematodes such as Ascaris have been known to survive for seven years or longer (Ensink & Fletcher, 2009). This means that there is a risk that these pathogens can be re-collected by percolating water and carried to groundwater.

Salts are particularly problematic in stormwater, as soil offers little attenuation. Water that contains salt after it has passed through the vadose zone will contaminate groundwater. Sulphate and potassium concentrations have been known to decrease with depth; however sodium, calcium, bicarbonate and chloride concentrations are all known to increase with depth. Common salt is particularly problematic in the northern hemisphere where it is used to de-ice roads (Burton & Pitt, 2002).

A summary of the most common compounds present in stormwater is shown in Table 12.2. This describes the potential of each of the compounds to contaminate groundwater making reference to the mobility, abundance in stormwater and filtration potential. The table shows that the groundwater contamination potential for a number of contaminants is reduced when pre-treatment is used before surface infiltration. The table also indicates that sub-surface injection of stormwater increases the risk of groundwater contamination. Of particular concern are enteroviruses and chloride contaminants that exhibit high potentials for groundwater contamination in all of the recharge methods. Owing to the fact that the public health risks are so variable and the assessment methods extremely complex, it is critical that the WSUD technologies and/or processes that are adopted can be interrupted at any time should the risk be exposed and that risk-based guidelines are developed for this practice.

Table 12.2: The various pollutants found in stormwater and their potential to contaminate groundwater (Pitt *et al.*, 1994)

Pollutants	Compounds	Mobility (worst case: sandy / low organic soils)	Abundance in stormwater	Fraction filterable	Contamination potential for surface infilt. and no pretreatment	Contamination potential for surface infilt. with sedimentation	Contamination potential for sub-surface injection with minimal pretreatment
Nutrients	Nitrates	mobile	low/moderate	High	low/moderate	low/moderate	low/moderate
Pesticides	2,4-D	mobile	Low	likely low	Low	low	low
	γ-BHC (lindane)	intermediate	moderate	likely low	Moderate	low	moderate
	Malathion	mobile	Low	likely low	Low	low	low
	Atrazine	mobile	Low	likely low	Low	low	low
	Chlordane	intermediate	moderate	very low	Moderate	low	moderate
	Diazinon	mobile	Low	likely low	Low	low	low
Other organics	VOCs	mobile	Low	very high	Low	low	low
	1,3-dichloro-benzene	low	High	High	Low	low	high
	Anthracene	intermediate	Low	Moderate	Low	low	low
	Benzo(a) anthracene	intermediate	moderate	very low	Moderate	low	moderate
	Bis (2-ethylhexyl) phthalate	intermediate	moderate	likely low	Moderate	low?	moderate
	Butyl benzyl phthalate	low	low/moderate	Moderate	Low	low	low/moderate
	Fluoranthene	intermediate	High	High	Moderate	moderate	high
	Fluorene	intermediate	Low	likely low	Low	low	low
	Naphthalene	low/intermediate	Low	Moderate	Low	low	low
	Penta-chlorophenol	intermediate	moderate	likely low	Moderate	low?	moderate
	Phenanthrene	intermediate	moderate	very low	Moderate	low	moderate
	Pyrene	intermediate	High	High	Moderate	moderate	high
Pathogens	Enteroviruses	mobile	likely present	High	High	high	high
	Shigella	low/inter.	likely present	Moderate	low/moderate	low/moderate	high
	Pseudomonas aeruginosa	low/inter.	very high	Moderate	low/moderate	low/moderate	high
	Protozoa	low/inter.	likely present	Moderate	low/moderate	low/moderate	high
Heavy metals	Nickel	low	High	Low	Low	low	high
	Cadmium	low	Low	Moderate	Low	low	low
	Chromium	inter./very low	moderate	very low	low/moderate	low	moderate
	Lead	very low	moderate	very low	Low	low	moderate
	Zinc	low/very low	High	High	Low	low	high
Salts	Chloride	mobile	seasonally high	High	High	high	high

12.3.2 Managed Aquifer Recharge (MAR)

Managed Aquifer Recharge (MAR) is a "*term applied to all forms of intentional recharge enhancement for the purpose of recovery for use or for environmental benefit*" (Dillion *et al.*, 2009). The different forms of recharge are shown in Figure 12.2 and include well known approaches such as Aquifer Storage and Recovery (ASR) and Aquifer Storage, Transfer and Recovery (ASTR). The successful application of ASR and ASTR in Australia and the United States of America (USA) over the past 40 years has resulted in increased levels of public acceptance. A number of applications in Australia have shown that ASR is capable of producing water of drinking quality standards (Dillon *et al*., 2009). ASR and ASTR can thus be economically attractive alternatives to other treatment methods such as desalination. Dillon *et al*. (2009) state that "*If 200Gℓ of the Water Services Association of Australia's projected 800Gℓ shortfall in water in Australian cities by 2030 were met from stormwater ASR, the cost savings in comparison with seawater desalination would be $400million per year in addition to significant environmental benefits*". Dillon *et al*. (2009) list a number of benefits of MAR techniques that include:

- Securing and enhancing water supplies.
- Improving groundwater quality.
- Preventing salt water intrusion into coastal aquifers.
- Reducing evaporation of stored water.
- Maintaining environmental flows and groundwater-dependent ecosystems, which improve local amenity, land value and biodiversity.
- Improving coastal water quality by reducing urban discharges.
- Mitigating floods and flood damage.
- Facilitating urban landscape improvements that increase land value.

In order to prevent over-abstraction of groundwater resources the WSUD approach encourages the utilisation of both stormwater and treated wastewater for MAR. This water is infiltrated or injected into the aquifer and re-used at a later stage for potable or for non-potable purposes, thereby reducing the demands on conventional potable water supply (Mudd *et al.*, 2004; Dillon, 2005). Appropriate conditions need to be in place for MAR to be successfully implemented, such as the availability of suitable aquifers and adequate storage capacity. It is also important that the aquifer that is used is protected by ensuring that the quality of water is maintained or improved and appropriate pressures are sustained to ensure the aquifer and aquitard (see Glossary for definition) structures remain intact (Water by Design, 2009). Other areas of concern are the clogging of boreholes and extraction of aquifer sediments, the mobilisation and build-up of contaminants, and loss of permeability due to changes in bio-geochemistry (Hancock, 2000; Mudd *et al.*, 2004). Before implementing an MAR scheme it is imperative that the following potential impacts are thoroughly researched and understood (Mudd *et al.*, 2000; NRMMC, 2009), failing which MAR may be excluded as a viable option for future development:

- The quality of water in the aquifer proposed for MAR – too high a water quality would risk contamination of a valuable potable resource and too low may threaten the quality of recovered water.
- The environmental value of the aquifer.
- The aquifer's current uses and the implications of MAR.
- The permeability of the aquifer.
- The impacts of increases or decreases in aquifer pressure.
- The potential for mineral dissolution and subsequent aquifer collapse.

Further general information on MAR in a South African context as well as specific detail on implementing successful artificial recharge projects can be found on the Artificial Recharge website developed by Groundwater Africa for the Department of Water Affairs, www.artificialrecharge.co.za.

12.4 Groundwater in South Africa

12.4.1 Policy and legislation relating to groundwater

The management, use and protection of South African groundwater resources are incorporated in policy and law at a national level (Pietersen *et al*., 2012).

Table 12.3 lists the various groundwater related topics and associated provisions in current government policy.

Groundwater is broadly recognised in the National Water Policy (NWP) of 1997 (RSA, 1997b) and the National Water Act (NWA), Act 36 of 1998 (RSA, 1998a) in terms of the regulation of its use and conservation. Groundwater has also been addressed in other areas of South African legislation such as the National Environmental Management Act (NEMA), Act 107 of 1998 (RSA, 1998c) and the Minerals and Petroleum Resources Development Act, Act 28 of 2002 (RSA, 2002), which outlines the obligations of mining and other industries to monitor and remediate pollution of all water resources including groundwater. The NWP and NWA are guided by the principles of Integrated Water Resources Management (IWRM) and therefore recognise water as an environmental, social and economic resource that is treated as a common resource to all people. This holistic approach common to both the NWP and NWA considers water in terms of the complete water cycle including groundwater.

Table 12.3: Provision for groundwater in RSA's National Water Policy
(Pietersen *et al.*, 2012)

Topic	Groundwater Provisions
Rights and access to groundwater	• All water is part of an interdependent water cycle; a resource common to all.
	• Equity in access for all South African citizens to water services, water resources and benefits from usage.
	• No ownership but only a right to environmental and basic human needs (Reserve) and authorisation for its use.
Groundwater allocation	• Allocation licensing policy (registration of new wells, drillers; groundwater use in the context of catchment management plan).
Protection of water resources	• Resource directed measures – setting clear objectives for protection of resources (classification, Reserve determination and resource quality objectives, RQOs; DWAF, 2000).
	• Source-directed measures – control and ensure that objectives are met.
	• Artificial recharge strategy (DWAF, 2007).
Climate change impacts and adaptation	• Develop pro-active and pre-emptive approaches in water-related disaster prevention.
Conjunctive use and management	• Water conservation and utilisation policy.
	• Water development in accordance with integrated environmental management.
Groundwater monitoring	• Detailed account of resource monitoring and information management.
Water pricing	• Water pricing policy.
Transboundary water management	• Southern African Development Community (SADC) Protocol on Shared Water Course Systems.
Institutions for water management	• National (DWA), regional (catchment management agencies; CMAs) and local (irrigation boards).
Stakeholder participation	• An integral part of South Africa's water sector reform.

There was also recognition in the first edition of the National Water Resources Strategy, NWRS-1 (DWAF, 2004a) that the requirements for the management of groundwater differ from surface water resources. Despite a general inclusion of groundwater in South Africa's national water policy however, shortcomings were identified in various aspects of the NWA as well as in the 1st edition of the NWRS, as summarised in Table 12.4.

Table 12.4: Shortcomings with respect to groundwater in RSA's NWA and NWRS-1
(Pietersen *et al.*, 2012)

Topic	Shortcomings in groundwater policy
Controlling groundwater use	• Licensing of groundwater unclear (regulation of local governments).
	• Only 20% of applications processed.
	• Limited capacity within DWA.
Regulating construction of wells and boreholes	• No explicit regulation.
	• Only technical guidelines and procedures for drilling, testing and sampling.
Controlling groundwater pollution	• Waste discharge levy system not yet implemented.
	• Inadequate groundwater monitoring networks.
Linkages with other legislation, National Environmental Management Act (1998) and Minerals and Petroleum Resources Development Act (2002)	• DWA and Department of Environmental Affairs (DEA) may require groundwater users to obtain a licence and environmental authorisation.
	• The two departments follow different procedures for assessment.
	• No effective co-operative governance procedures in place.
	• Mines operating without water-use licences.
	• Mining permits issued without due consideration for water-use consequences.

Some of these shortcomings include the limited regulation of the use and users of groundwater, lack of groundwater protection through penalty systems or groundwater monitoring, and the lack of co-operation between government departments. As a consequence, the National Groundwater Strategy (DWA, 2010c) and the Artificial Recharge Strategy for South Africa (DWAF, 2007) were produced and have served as input to the 2nd edition of the NWRS (DWA, 2013). The NWRS-2 now includes several strategic actions regarding groundwater management and use, including promoting on a larger scale the use of groundwater as an appropriate source of water for increasing water supply, and recognising that groundwater recharge is critical ecological infrastructure for supporting water security and should therefore be maintained and restored to support water quantity and quality (DWA, 2013).

12.4.2 Groundwater in South African metropolitan areas

In RSA the responsibility of groundwater management is spread over a range of water institutions, such as the DWA, Catchment Management Agencies (CMAs), Water Services Authorities (WSAs), Water Services Providers (WSPs) and Water User Associations (WUAs), as shown in Table 12.5. Most of the municipalities in RSA adopt the function of a WSA

(DWAF, 2003), and according to Riemann (2012), WSAs have a responsibility to promote aquifer protection and sustainable utilisation through land use planning, monitoring, groundwater assessment, licensing, planning and monitoring (Table 12.5). Riemann (2012) proposes the development of a groundwater management framework for municipalities that addresses how groundwater should be protected and utilised, as well as the different roles of water institutions in groundwater management (Figure 12.3). Based on this there is a clear mandate for municipalities / WSAs to consider the utilisation and protection of groundwater.

Table 12.5: Government responsibilities in terms of groundwater management
(Riemann, 2012)

	DWA / DEA	CMA	LM / DM	WSA	WSP	WUA	Water user / Polluter
Aquifer protection							
Land-use planning		X		X		X	
Waste management	Reg.		X				
Effluent quality management	Reg.				X		
Groundwater remediation	Reg.						X
Groundwater monitoring		X		(X)		X	X
Aquifer utilisation							
Groundwater assessment				X			
Licensing	X			(X)			
Well-field planning and design				X	(X)		
Well-field operation and maintenance					X		X
Groundwater monitoring				X	X		X
Reg. = Regulator	**X = Main responsibility**				**(X) = Input, partial responsibility**		

The Water Services Act (RSA, 1997a) and the Strategic Framework for Water Services (DWAF, 2003) stipulate that all WSAs are required to develop a Water Services Development Plan (WSDP), which should be included in the Integrated Development Framework (IDF). The aim of the WSDP is to assist WSAs in terms of environmental, social, financial and institutional planning of water resources (DWAF, 2003). The WSDPs and IDFs along with other groundwater-related municipal regulations, provide an indication of the way in which metropolitan areas in RSA place value on, and manage groundwater resources.

The manner in which the different municipalities deal with groundwater varies. In some areas for example, groundwater is utilised as an available (or potentially available) resource, while in other areas it may not be suitable for use owing to high levels of salinity, or it could be seen as unnecessary for bulk water supply due to the abundance of surface water. From a groundwater perspective, WSUD does not focus solely on current groundwater use, but rather seeks to develop adaptive thinking around protecting and developing groundwater as a resource connected to the urban water cycle – thereby building resilience. Thus, the WSUD approach could provide a means for WSAs to start attaching value to groundwater, and to begin to monitor, evaluate and understand the risks and opportunities associated with its use, as well as the costs of not protecting it as a resource. Some current practices are described in the next few paragraphs.

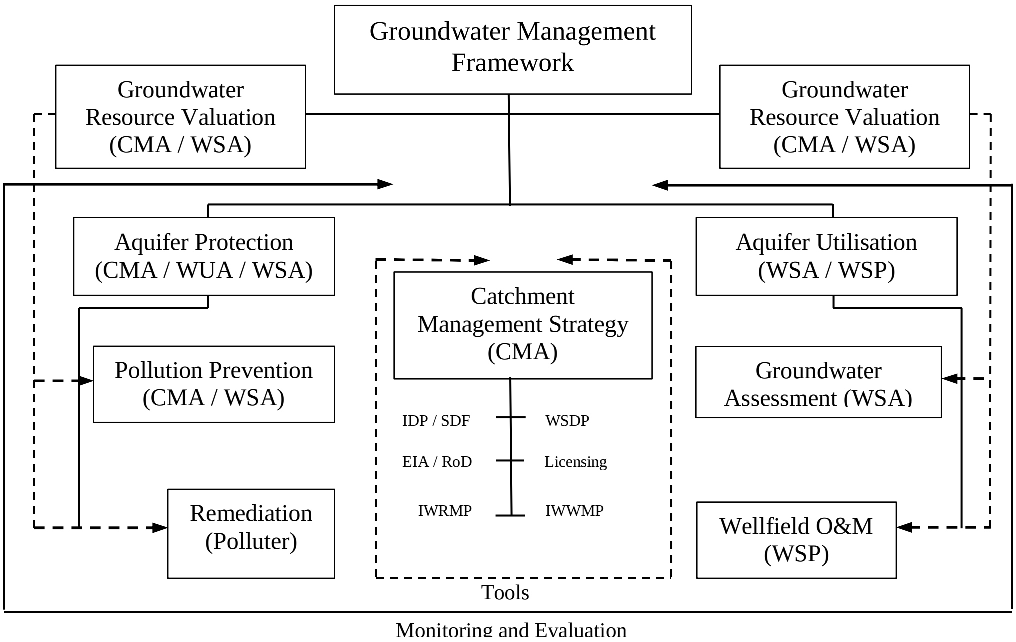


Figure 12.3: Proposed groundwater management framework addressing 'Aquifer Protection' and 'Aquifer Utilisation' and the main available tools (after Riemann, 2012)

The City of Johannesburg has incorporated groundwater into its WSDP and acknowledges groundwater as a valuable resource that that could potentially be used for bulk water supply and which requires protection if it is to be available for future use. There are however problems regarding Acid Mine Drainage (AMD) – the flow of heavily contaminated water from old mining areas – in the Johannesburg area, and its potential impact on the quality of groundwater in the area. The monitoring of groundwater in Johannesburg is relatively poor and the majority of the established groundwater monitoring network is out of service (CoJ, 2009). A study investigated the restoration of the monitoring boreholes and the expansion of the monitoring network over the entire city; however this proved to be unfeasible due to financial constraints (CoJ, 2009).

The City of Tshwane has historically used groundwater as a water supply source, and currently parts of the CBD and the suburbs to the east and west of the city centre still use groundwater. The City receives approximately 57 Mℓ/day of water from groundwater springs and boreholes south of the city (Dippenaar, 2013a). Groundwater is used in other areas around

Tshwane; however, because the groundwater is sourced from dolomitic areas, there is a fear of creating structural instability in the subsurface. There is thus an increasing shift towards surface water supply through WSPs, such as Rand Water and Magalies Water (Hilder, 2012). It should be noted that Tshwane is also under threat of AMD (Gauteng Province, 2006).

The City of Cape Town has access to a number of groundwater resources such as: the Albion Springs, Atlantis Aquifer, Table Mountain Group (TMG) Aquifer, the Cape Flats Aquifer and the Newlands Aquifer. Currently, only the Albion Spring and the Atlantis Aquifer are used for bulk water supply. The City of Cape Town actively promotes groundwater use for urban irrigation. However, this usage is largely unregulated and the only requirement is that households using groundwater for irrigation purposes must indicate, by way of a notice fixed on the property, that water is being used from a well-point or borehole. The benefit of using groundwater for household irrigation is that it reduces the demand on potable water supply. The City's WSDP is set to include consideration of increasing future groundwater abstractions. Currently, a feasibility study is being conducted on the Table Mountain Group (TMG) Aquifer, with future feasibility studies on the Newlands Aquifer and Cape Flats Aquifer also under consideration.

The WSDP for the eThekwini Municipality (which includes Durban) shows no plan for the inclusion of groundwater management. The KwaZulu-Natal Groundwater Plan published by DWAF (DWAF, 2008) suggests however that groundwater in eThekwini is mostly used for industrial purposes and that the groundwater is heavily polluted. It also suggests that groundwater monitoring in eThekwini is poor, with an overall lack of data management (*ibid*).

12.5 Groundwater management best practice

Sustainable groundwater development is critical for urban planning and management (Collin & Melloul, 2001; Morris *et al*., 2001); however, if groundwater management is to be successfully achieved then a strong institutional framework is required which includes the regulation of groundwater. Even if the appropriate institutional framework and legislation is in place, there still needs to be public and political will to manage and protect groundwater. In many instances groundwater management is not politically attractive as it may only yield benefits in the long term (Foster *et al*., 1998). Another issue is that there is often a lack of foresight regarding the development of groundwater resources. The installation of boreholes, in the initial stages of groundwater development, is often unplanned and unregulated.

In general, groundwater management in urban areas is mostly concerned with improving or maintaining the appropriate quantity and quality of groundwater at the lowest cost, while preventing irreversible degradation (Todd & Mays, 2005). This can be enforced using specific regulatory codes or through planning and consultation (Foster *et al.*, 2010). The quantity of groundwater is dependent on the levels of recharge and abstraction which need to be carefully monitored (Foster *et al.*, 2010). Whilst there is frequently a desire to license groundwater users, this is difficult in an urban context, particularly in a developing country, where most of the abstractions of groundwater are unregulated or illegal (Foster *et al*, 2010). Nevertheless, the quality of groundwater requires legislative and monitoring controls that prescribe the disposal of liquid effluents and solid waste, as well as other activities that could pollute groundwater.

12.5.1 Groundwater considerations for WSUD Best Management Practices

Water by Design (2009) provides a detailed outline of the Best Management Practices (BMPs) with regard to WSUD techniques and technologies. Groundwater is considered in most of the WSUD BMPs in terms of its potential for storage or as a constraining physical characteristic, both in terms of quantity or quality (Water by Design, 2009). A high water table is a limiting factor for a number of WSUD BMPs, including stormwater harvesting, pollutant capture and infiltration devices, as well as wastewater treatment methods. For example, most design guidelines specify that the bottom of an infiltration pond should be at least one meter above the seasonal high water table (Water by Design, 2009). High water tables often preclude the implementation of a number of WSUD devices as saturated conditions can aid the mobility of pollutants in the soil profile which may cause groundwater contamination. Furthermore, high water tables are counter-productive to water quality improvement, for example infiltration devices that require infiltration through an unsaturated soil profile for the removal of contaminants.

12.6 Groundwater processes: Measurement and monitoring

12.6.1 Hydrological Data

Hydrological data such as rainfall, streamflow and groundwater levels are critical to understanding catchment behaviour, testing management scenarios and calibrating hydrological models. The availability of this data varies from place to place, with rainfall and streamflow data being more readily available than groundwater data in an urban context. Groundwater data – in particular, groundwater levels, but also water quality – are important for determining the state of groundwater resources of a particular site and the hydrogeological processes that characterise that groundwater such as the likely recharge, flow direction and potential interaction with surface water. Measurement of soil moisture, soil and geological structure will help to describe how infiltration and groundwater recharge, which is influenced by soil and geological structure. Soil and geological structure can be investigated using borehole logs to investigate the soil and geological properties of a borehole profile, and by using Electrical Resistive Tomography (ERT). ERT measures the subsurface resistivity which is a function of geological and hydrological factors such as rock / soil type, grain size, porosity and pore fluid properties (Uhlenbrook *et al*., 2008; Koch *et al*., 2009). The electrical resistivity of subsurface properties is measured by inducing a current through an array of current electrodes inserted into the ground surface and the resistivity is measured by potential electrodes that receive the electrical signal (Riddell *et al*., 2010). The subsurface resistivity can then be interpreted based on areas of homogeneous resistivity with particularly low resistivity’s being associated with subsurface water. Figure 12.3 shows an example of the application of ERT for hydrological studies. The red and purple areas are of high resistance, such as clay, whereas the blue areas, which are lower in resistivity, indicate the presence of water. A number of hydrological studies (Riddell *et al*., 2010; Uhlenbrook & Hoeg, 2003; Uhlenbrook *et al*., 2008; Wenninger *et al*., 2008) have used ERT to assist the interpretation of hydrogeological processes. This data is also valuable for aiding the parameterisation, calibration and validation of physically-based models.

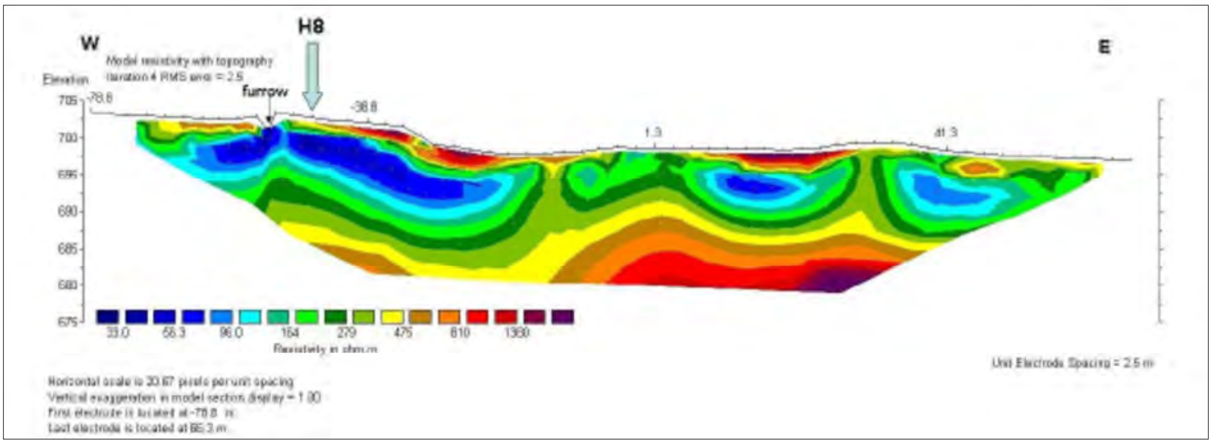


Figure 12.4: Example of the application of ERT for hydrological process identification
(Riddell, 2010)

12.6.2 Flow processes

Describing the flow of water in a particular hydrological system is important for assessing the applicability of WSUD techniques and technologies. With a greater understanding of the processes that govern infiltration, recharge, baseflow and streamflow in urban areas, it is possible to gain further insight into the benefits and potential limitations of WSUD techniques and technologies. One way of investigating the processes that govern infiltration, recharge, baseflow and streamflow / stormflow in urban areas is the uses of hydrological tracers. Tracers provide insight into the source components of streamflow, the rate of groundwater recharge, residence times and flow pathways of the hydrological system. The most established application of isotopes in hydrology is for determining the source components of stormflow using hydrograph separations. Hydrograph separations using tracers allow a stormflow data series to 'separated' into the different source components (i.e. groundwater or runoff) from which the stormflow was generated. There are a variety of tracers available for hydrological applications. Some tracers are artificially introduced into the system being studied, such as urinine, while others occur naturally within the hydrological cycle *viz*. stable isotopes such as ^{18}O and ^{2}H (Deuterium) and hydrochemical tracers such as pH, electrical conductivity or the concentration of different anions and cations (Christophersen *et al*., 1990; Uhlenbrook & Hoeg, 2003). Stable isotopes (oxygen-18 (^{18}O) and deuterium (^{2}H)) (Buttle, 1994; Shanley *et al.*, 2002; Uhlenbrook & Hoeg, 2003; Wenninger *et al*., 2008), dissolved Silica (Pellerin *et al.*, 2008; Uhlenbrook & Hoeg, 2003; Wenninger *et al*., 2008), electrical conductivity (Liu *et al*., 2013; Santhi *et al*., 2008) are commonly used for hydrograph separation analysis.

12.7 Groundwater monitoring and data requirements

The monitoring of water resources, including groundwater, is mandated in Chapter 14 of the NWA. The Act stipulates that water resources should be monitored, measured and recorded, particularly for the purpose of developing a national water resources information system. This information system is outlined in the NWA to address the data requirements of all water resources, ranging from the quantity and quality to rehabilitation and legal compliance. As indicated in Section 12.4.2 of this report, the duty to monitor groundwater is vague; however recent work by Riemann (2012) indicates that various water institutions are required to monitor groundwater.

Monitoring is a critical aspect of groundwater management, providing a baseline for management objectives, maintaining human health standards, and ensuring adherence to groundwater legislation (Australian Department of Water, 2011). Monitoring groundwater also enables the early detection and diagnosis of potential groundwater problems, helping to avoid irreparable damage (Foster *et al*., 2010). Effective groundwater management requires detailed data however, which may require monitoring at a local scale (Dennis, 2007). Unfortunately groundwater suffers from a general lack of monitoring, particularly in the developing world where the shortage of human and financial resources required to sustain groundwater monitoring networks is a major barrier (Morris *et al*., 2001). Moreover, the lack of ability to implement legislation or to investigate potential problematic areas due to problems with institutional capacity often renders monitoring efforts ineffective (Foster *et al*, 2010).

Monitoring is also important for calibration and validation of groundwater flow models. These models require an array of input data, depending on the specific modelling objectives. In general, hydraulic conductivity, specific storage, aquifer conditions and groundwater recharge data are required. Other information might include: maps of geology, topography, aquifer thickness and confining layers, water table and potentiometric measurements, as well as other hydrological information, such as precipitation, evapotranspiration, groundwater-surface water interaction and groundwater pumping. Groundwater quality is also important for contaminant studies (Wolf *et al*., 2006).

In South Africa groundwater data from selected boreholes is contained in the National Groundwater Archive. This database is useful in providing information on water levels and groundwater quality; however these figures are often inaccurate or are recorded at irregular intervals. Other data, such as hydraulic conductivity and aquifer characteristic may require site specific measurement. Geological and topographical maps and hydrological records are readily available in South Africa (DWA, 2010c). Without measurements of groundwater quantity and quality it is difficult to manage groundwater and this limits the ability to test groundwater flow and contaminant transport models. If the sustainable use and protection of urban aquifers is the aim in South Africa, then monitoring will be essential to achieving these goals.

12.8 Concluding remarks on groundwater as a component of WSUD

WSUD draws attention to the value of groundwater in general. This is particularly important in South Africa where groundwater is undervalued. There is a need to consider the interaction of groundwater with urban infrastructure, ecosystems and storage and thus identify the risks and opportunities of groundwater use. It is important that groundwater experts are included in the identification of the risks and opportunities associated with groundwater interactions in WSUD, so that there is an opportunity to formulate a suitable response in terms of mitigating these risks and optimising the opportunities. For example, if an aquifer was at risk of contamination the appropriate response from a WSUD perspective would be to conserve and protect that resource from further damage. Alternatively, in a case of an aquifer that is available for use there may be an opportunity to recharge the aquifer to increase its long term yield while encouraging water re-use. The WSUD approach to urban water management is holistic and therefore risk mitigation and opportunity optimisation need to occur simultaneously.

The use of groundwater as a resource should be considered a key part of the WSUD approach based on the fact that it is intimately linked to ecological goods and services. Additionally, groundwater protection measures are required to ensure sustainability of urban aquifers. WSUD encourages all urban water stakeholders' to attach value to groundwater and to begin to monitor, evaluate and understand urban groundwater processes. The risks and opportunities associated with urban groundwater use, as well as the costs of not protecting urban groundwater can then be derived.

13. Sustainable water supply

Ensuring the sustainability of South Africa's water supply requires a move beyond the construction of large scale water supply schemes to satisfy the growing demand for water. Water is a scarce resource and it is imperative that water management strategies begin to make use of the available water resources in the most efficient and effective manner. Here, the concept of 'sustainable water supply' is used to describe the alternative approaches needed to secure South Africa's water resource requirements. Sustainable water supply can be defined as the use of water in a manner that does not deplete or permanently damage the resource. Sustainable water supply strategies aim to have an impact on the urban water cycle; reducing potable water supply requirements, minimising wastewater generation, and maximising the use of alternative water sources. Figure 13.1 illustrates how sustainable water supply strategies affect the various streams of the urban water cycle.

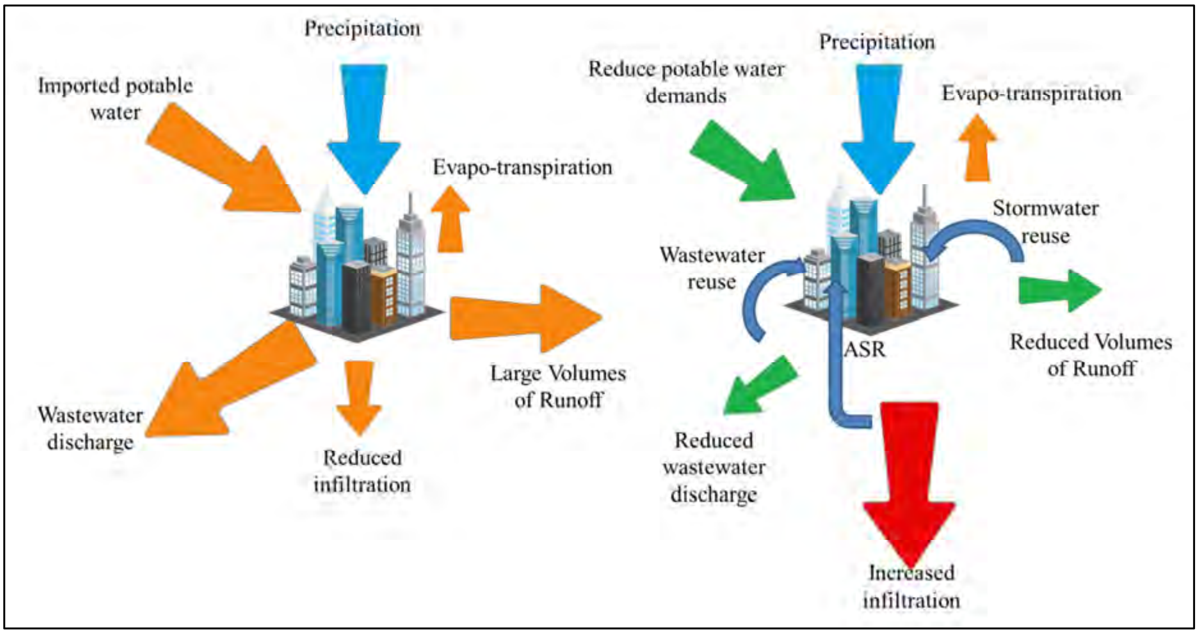


Figure 13.1: The impact of sustainable water supply strategies on the urban water cycle (adapted from Hoban & Wong, 2006)

13.1 Water Conservation and Demand Management

As highlighted previously in sections 5.3.1 and 10.3.2.3, there are significant challenges with respect to water losses in general and non-revenue water (NRW) in particular throughout SA urban supply systems (McKenzie *et al*., 2012). While some municipalities and other institutions have begun to address these challenges, it has become apparent that efforts must be intensified with specific targets set to reduce water losses. Water Conservation and Water Demand Management strategies (WC and WDM) aim to improve the sustainability of urban water use and have multiple benefits in terms of the postponement of infrastructure augmentation, mitigation against climate change, support to economic growth and ensuring that adequate water is available for equitable allocation. As South Africa's conventional water supply options approach their full potential and it becomes increasingly expensive to develop further resource capacity, WC and WDM offer a more economical means of balancing the country's water demands with its available supplies (DWAF, 2004b). The definitions of WC and WDM are very closely aligned as follows:

- **Water Conservation (WC)** refers to the minimisation of water loss or waste, the care and protection of water resources, and the efficient and effective use of water (DWAF, 2004b).
- **Water Demand Management (WDM)** refers to any action or process that promotes the more efficient and sustainable use of water resources (Deverill, 2001; Savenije & Zaag, 2002). The definition for WDM adopted by the Department of Water Affairs expands the scope of the definition to incorporate a range of issues such as social development, social equity, political acceptability and economic efficiency (DWAF, 2004b).

13.1.1 Linking WC, WDM & sustainable water supply

WC and WDM differ in that WC engages with the broader principles and objectives of sustainable resource use, whereas WDM mainly focuses on the operational strategies available to achieve the goals of sustainable water supply (Figure 13.2). Furthermore, Braun (2007) stresses the nature of WDM as one that engages with more than just technological interventions and considers the concept as a governance approach to change the ways and rate at which water is utilised. There is also a need to look beyond the quantitative aspects of water consumption and to consider the time and space dimensions of water use, as well as the implications of water quality (Braun, 2007). Figure 13.2 illustrates how WC and WDM relate to the broader, holistic concept of sustainable development, otherwise known as ecologically sustainable development (ESD). WC incorporates the principles of ESD with a specific focus on water resources, while WDM engages with the sustainable water supply strategies relating to all three streams of the urban water cycle.

13.1.2 The objectives of WDM

It is important to note that the WDM concept transcends the demand-side paradigm and incorporates all components of the urban water cycle, including issues relating to supply-side management. The definitions of demand-side and supply-side management focus on the two major components of water distribution, supply and consumption (CoCT, 2007a).

- **Demand-side management** refers to any measure which results in the reduction in expected water usage or demand.

- **Supply-side management** refers to any measure that will increase the capacity of a water resource or water supply system to supply water.

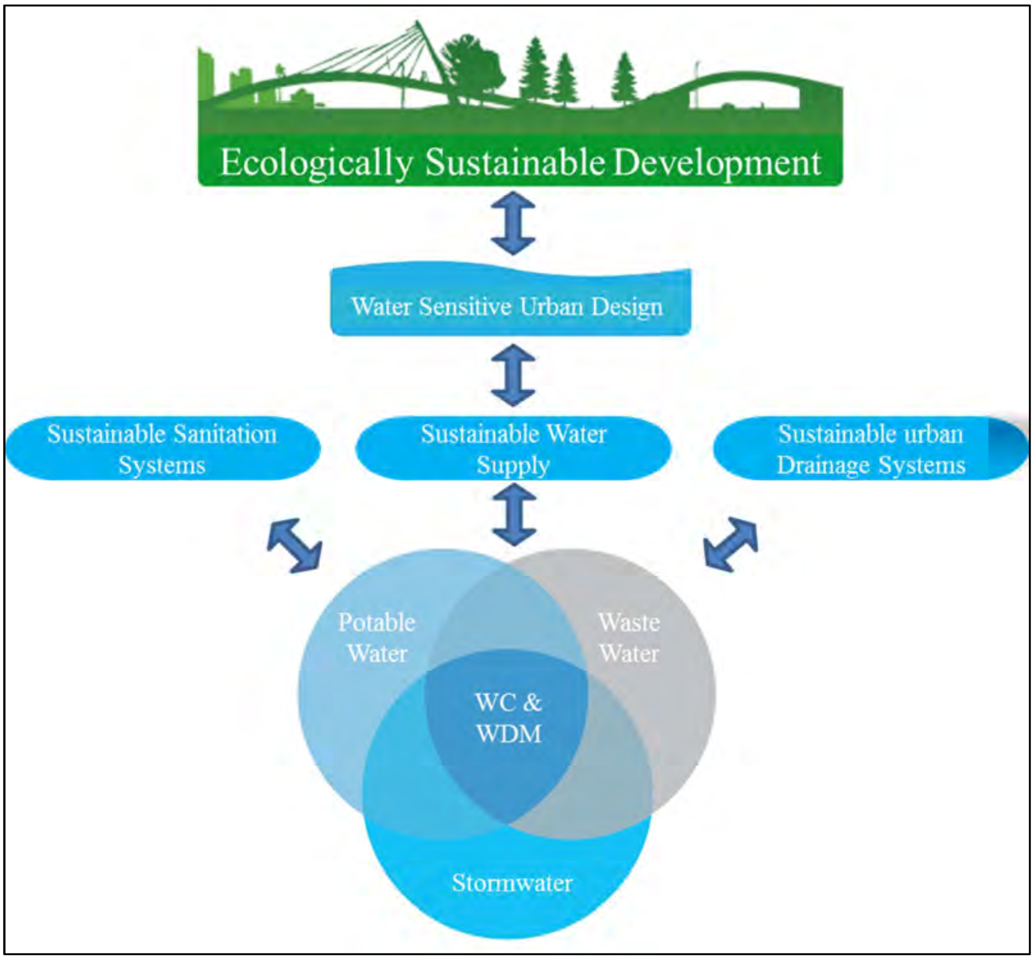


Figure 13.2: The relationship between ESD, WSUD, WC and WDM
(Hoban & Wong, 2006)

The strategies that can be used to reduce water use and improve efficiency of use from both the supply and demand side can be separated into four categories (Flack, 1981; Still *et al.*, 2008):

i) **Structural methods**, which refer to physical infrastructure interventions that improve the efficiency of the distribution system as well as water efficient technologies that reduce the quantities of water required to perform a specific function.

ii) **Operational methods**, which refer to the operational strategies aimed at improving efficiencies within the distribution system and include options such as pressure management systems and leak detection and repair programs.

iii) **Economic methods**, which include all aspects of cost recovery as well as ensuring that marginal water use is given it real marginal value.

iv) **Socio-political methods**, which refer to the education and awareness campaigns as well as laws and regulations that act as 'push factors' to move consumers towards a water efficient state.

Given the complex nature of water supply systems, it is inevitable that the strategies adopted by demand-side and supply-side approaches overlap. Benefits achieved through one approach very often benefit the other; for example, reducing water losses is a key component of demand side strategies, but also forms one of the key issues associated with supply-side approaches.

In view of the all-encompassing nature of the WDM concept with regard to the sustainable management of water resources, these guidelines will adopt WDM as the basis for the principles of sustainable water supply. WDM strategies aim to cover a wide range of aspects relating to the quantity, quality, and the time space dimensions of water use. There are many places to intervene along the water supply chain, from the collection of water from natural catchments to its consumption and disposal after use. In order to avoid separating supply and demand side approaches, the various WDM strategies may be categorised under three broad objectives:

i) **Reducing non-revenue water (NRW) –** NRW refers to water that does not yield any revenue either as a result of being lost to system leakage, billing or metering errors, or non-payment by consumers. Strategies focusing on reducing non-revenue water and managing water losses are generally concerned with the effective management of the water distribution network (i.e. reducing leaks), the billing system used to collect revenue, and the strategies used to reduce the levels of non-payment by consumers.

ii) **Reducing water wastage at the point of consumption –** this focuses on strategies that influence consumer behaviour: regulation, consumer awareness, education campaigns, informative billing, and incentive schemes all of which play a role in helping to create water-wise consumers. Improving technical efficiency alone is not sufficient, sustainable water supply is heavily dependent on a proactive consumer base that aims to maximise consumption efficiency and minimise water wastage.

iii) **Replacing potable water on a 'fitness for purpose' basis –** this refers to the need to source alternative water supply options (e.g. rainwater / stormwater, wastewater / greywater; groundwater, seawater, etc.) where appropriate and feasible to supplement existing water supplies and create a more diverse and resilient water supply strategy. It is clear that South Africa will need to diversify its water supply options in order to meet the growing water supply needs (DWAF, 2004a).

13.2 Overview of WDM strategies

Figure 13.3 illustrates some of the more common strategies available to improve the sustainability of water supply through the application of the three objectives of WDM.

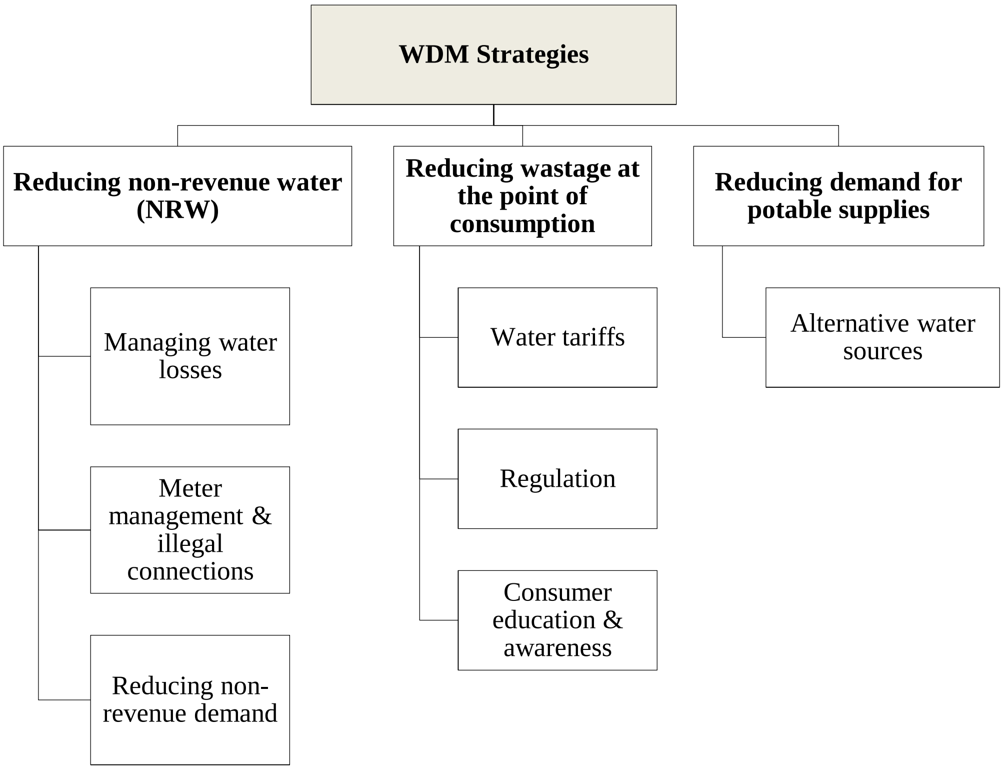


Figure 13.3: An overview of WDM strategies

13.3 Reducing non-revenue water (NRW) losses

13.3.1 Managing water losses

The first step to improving the sustainability of water supply is to reduce the quantity of water lost as a result of network leakages. The two primary mechanisms used to manage water losses through leakage can be categorised into passive leak control and proactive leak control measures. Proactive measures involve pressure reduction and leak detection schemes, while initiatives around operation and maintenance make up the passive leak control measures.

13.3.1.1 Reducing reticulation losses through pressure reduction and leak detection

Water reticulation networks are required to provide water at a specified minimum pressure during periods of high demand. During periods of low demand, particularly at night, these pressures are significantly higher which results in increased quantities of water loss as well as a higher incidence of pipe bursts. Pressure management aims to lower the water pressures during periods of low demand to mitigate the negative impacts associated with high pressures in the reticulation system. Further information regarding pressure management can be found in a report entitled "*Leakage reduction through pressure management in South Africa*" by Mckenzie *et al.* (2002).

Leak detection strategies are a vital component on any water management strategy, and play a major role in reducing water losses. Leak management consists of two primary activities: leakage monitoring and leakage control. Leakage monitoring involves the placement of flow rate meters at strategic locations on the reticulation system; each meter then measures flows into a particular sector of the network with a defined boundary, known as a District Meter Area (DMA). The objective of this approach would be to divide the distribution system into a number of DMA's with the least practicable number of meters to continuously monitor night flows and locate pipe bursts and leakage (Pilcher *et al.*, 2007). The information gathered from the leakage monitoring of the DMA's is then used to prioritise leak control initiatives. Leak detection initiatives can be conducted as a routine check of the reticulation system or as a result of higher than normal flow measurements from a DMA. Leak detection involves two broad approaches: leak localising and leak location, the former being the isolation of a leak to a section of pipe and the latter being the pinpointing of the specific location of the leak. There are a range of methods available to pinpoint leakage points, the most common relying on acoustic sensors to pick up on noise generated by leaking pipes.

13.3.1.2 Proactive operation & maintenance

Effective operation and maintenance (O&M) of water supply infrastructure is a critical component of any WDM strategy. O&M strategies tend to be reactive, where network failures govern maintenance activity. This approach has costly consequences as infrastructure ages and surpasses its design life leading to poor performance of the system as a whole. This issue is so prominent on a global scale that it is anticipated that the rehabilitation of reticulation systems stands to present one of the greatest civil engineering challenges for cities around the world (CoCT, 2007a). A comprehensive O&M strategy which incorporates proactive network rehabilitation provides a solid basis for tackling the challenge of aging infrastructure, and helps to significantly reduce reticulation losses and the frequency of pipe bursts. Along with network rehabilitation strategies, preventative maintenance provides an opportunity to prolong the lifespan of existing infrastructure and improve system performance with regard to service delivery and water losses.

13.3.2 Meter management & unauthorised connections

It is estimated that up to 50% of non-revenue water in South Africa can be credited to apparent losses (CoCT, 2007a). As the name suggests, apparent losses refer to water that appears to have been lost through leakage but is actually 'lost' as a result of meter errors, billing errors, and unauthorised consumption.

No water meter is perfectly accurate and whilst there are guidelines in the South African Bureau of Standards (SANS 1529) for the required accuracy of meters over a range of flow rates there remains a significant error in the recording of flows. Furthermore, over time the accuracy of a water meter deteriorates with age, and is particularly poor at low flow rates where meter accuracy is lowest (Van Zyl, 2011). Accurate metering is important and it is essential for effective cost recovery as well as most planning, operation and maintenance functions (CoCT, 2007a). Managing apparent losses due to meter under-registration usually means replacing inaccurate meters; however given the sheer number of meters in a distribution network the task is immense. From a management point of view, the simplest approach is to replace the meters after a fixed time period, however this is not the most economic approach and a more sophisticated meter replacement program is required. One method involves the use of GIS based software to identify anomalies in consumption data that could point to faulty metering. Other methods would involve responding to consumer complaints or exception reports of suspected meter errors that emerge from the billing cycle.

Another source of non-revenue water results from illegal connections to the water network. Illegal connections can come in several forms (CoCT, 2007a):

- Illegal consumption from fire hydrants.
- Illegal connections by consumers who are not currently serviced.
- Illegal connections by consumers who are authorised for a lower level of service.
- Illegal connection by developers or construction companies.

Although there is a need to eliminate these illegal connections, disconnecting consumers can be a very sensitive issue as very often the consumers are not currently serviced by the municipality. It is vital that appropriate policies and procedures are formulated to manage the disconnection process. Further information regarding effective meter management can be found in *An introduction to integrated water meter management*, by Van Zyl (2011).

13.3.3 Reducing non-revenue demand

In South Africa, water management strategies need to pay particular attention to the urban poor, specifically in terms of capacitating consumers and enabling them to take responsibility for their water services (CoCT, 2007a). This could be achieved through strategies centred on reducing domestic water leakage in low-income areas. Initiatives centred on leak detection and repair at a community level could have a significant impact on reducing water losses and decreasing NRW. The implementation of debt management strategies (initiatives such as easy payment schemes or writing off arrears to help create a more functional billing system and improve cost recovery) could also help in encouraging consumers to reduce their water demand to affordable levels (or to within the Free Basic Water allowance) in order to avoid problems of debt in the future (*ibid*).

13.4 Reducing water wastage at the point of consumption

13.4.1 Water tariffs

The long term sustainability of any water supply scheme is governed by its financial viability; water tariffs are a vital component of any water management strategy and aside from the cost recovery aspects, they also play an important WDM role. There is a delicate balance to be struck between the use of tariffs as a source of income generation and as a tool for achieving the WDM objectives of reducing overall water demand. Pricing incentives / tariff structures can be used as part of a suite of tools to reduce water consumption, but may not be effective as a control mechanism on their own (Arbués *et al*., 2003; Van Zyl *et al*., 2003). The challenge is to use these incentives to ensure adequate cost recovery and financial efficiency without compromising the overarching WDM goals.

13.4.2 Informative billing, equitable tariffs and incentive schemes

There are several innovative strategies relating to billing and tariff structures that could have a major impact on water consumption levels. One method of controlling consumption involves the use of pricing incentives in the form of rising block tariffs. Rising block tariffs involve the use of an increasing unit charge for successive blocks of water consumption. The objective of this approach is to ensure a basic level of consumption to all consumers and promote a stronger incentive for conservation at high levels of discretionary use (Foster, 1998). The block tariff system provides a useful cross-subsidisation mechanism allowing low income communities access to an affordable water supply while consumers who use large quantities pay a tariff related to the marginal cost of water (CoCT, 2007a).

Another method of influencing consumer behaviour is achieved through the use of informative billing. The concept involves providing the consumer with information regarding their monthly water use in a simple and effective manner. Information could include: a summary of the consumer’s water trends over a given period, how this compares with the municipal average, and possible savings of reduced consumption. Providing this information in a format that is easy to understand initiates a feedback loop to the consumers improving awareness of their individual consumption patterns.

Promoting the conservation of water through the use of incentive schemes could also form a useful strategy to promote the objectives of improved water use efficiency. Incentives such as fast tracking building approvals for new developments or environmental recognition schemes could be used to encourage a water sensitive approach to future developments. Although building codes and bylaws very often specify the need for water efficient appliances in all new developments, these incentive schemes provide a supplementary approach to achieving the WDM objectives. Incentives schemes can also be implemented at the level of the individual consumer. Subsidies for the purchase and installation of water efficient appliances, and recognition schemes for water efficient businesses are just two examples of incentives that could be used to promote improved water use efficiency. The management of an incentive scheme creates additional complexity to the water management strategy however and it is important that there is sufficient capacity within the municipality to manage the various incentive schemes.

13.4.3 Regulation: water conservation policies and by-laws

Although influencing consumer behaviour through incentive schemes and awareness campaigns can have a major impact on water savings, there is often a need for a strong regulatory framework through which the progress made at improving water use efficiency can be sustained. Policies and by-laws relating to the efficient use of water are critical to establishing standards and norms for the more efficient use of water. Compulsory building standards, water restrictions, and policy development around water wastage and improved water conservation provide the legislative backing for the implementation of WDM strategies and help drive the progression towards more sustainable water management.

The Water Services Act (108 of 1997) assigns the responsibility of managing water provision to local government (RSA, 1997a). It is therefore at this level that by-laws have to be promulgated to mandate a move towards the more efficient use of water. Table 13.1 highlights some of the policies and by-laws adopted by three of the major metros in South Africa: Cape Town, Johannesburg, and eThekwini. The by-laws adopted by the aforementioned metros are all based on the Model Water Services By-laws (DWAF, 2005) which provide recommendations intended to help municipalities with the development of their own by-laws relating to the supply of potable water (Still *et al.*, 2011). The provisions made in the Model By-laws regarding the conservation of water and prevention of water wastage include (*ibid*):

- Municipal consent for the installation of new pipes and fittings.
- Standards pertaining to the quality and installation of pipes and fittings.
- Powers of municipal authority to prevent wasteful use of water or to impose restrictions on the use of water in the event of water shortage, drought or flood.
- Prohibitions on the waste of water by consumers.
- Requirement of an annual water audit required by water users who consume more than 3650 kilolitres per annum.

In addition to these measures the CoCT (2011a) has also incorporated a comprehensive set of provisions relating to water demand management. These provisions enforce a range of measures that focus on promoting improved water conservation largely through enforcing consumer ‘best practice’, and the use of water efficient devices to minimise the quantity of water required to complete a specific task.

Table 13.1: Summary of legislation relating to water conservation

Local Authority	Policy/Bylaw	Status	Overview
City of Cape Town	Water By-Law	Adopted (CoCT, 2011a)	The purpose of the by-law, as stated in the opening abstract is "*to provide for the control and regulation of water services in the City; and to provide for matters incidental thereto.*"
	Water & Sanitation Asset Management Policy	Adopted (CoCT, 2011b)	The City's asset management policy provides a useful platform for the effective management of the water distribution system which aims to, "*…provide the highest quality water and sanitation services that meet and/or exceed the current and future service requirements and expectations of consumers by ensuring the implementation and application of sound infrastructure asset management practices and principles within the Department.*"
City of Johannesburg	Water Services By-Laws	Adopted (CoJ, 2008)	These by-laws aim to achieve the same general objectives as those adopted by Cape Town. They incorporate water restrictions as well as measures to prevent water wastage; however the concepts of WC & WDM are not included as these are covered in a separate municipal WDM strategy.
eThekwini Municipality	Water supply By-Laws	Adopted (eThekwini Municipality, 2013)	Like Johannesburg, the by-laws provide a framework for water restrictions and highlight the importance of minimising water wastage; however WC and WDM measures are not included.
	Water Conservation Guidelines	Adopted (Price, 2009)	The purpose of these guidelines was to "*provide information to consumers on how to save water by implementing a water use efficiency programme on residential, commercial and institutional properties*."

The most common form of regulation in South Africa's cities is the implementation of water restrictions. Several major cities have implemented water restrictions in an attempt to reduce consumption. The City of Cape Town Water Services Development Plan (CoCT, 2006b) stipulates three levels of water restrictions: Level 1 restrictions attempt to achieve a 10% reduction in water consumption, while Levels 2 and 3 restrictions seek to achieve 20% and 30% reductions respectively. The various levels of water restrictions require varying levels of restriction with the 30% reduction requiring more stringent restrictions.

13.4.4 Consumer education and awareness campaigns

There are numerous methods for improving the efficiency of water supply systems through technological innovation which, in the absence of significant population growth, may obviate the need for the augmentation of bulk water supply schemes. Improving efficiency to delay the need for massive capital investments into additional water supply has obvious benefits in terms of addressing the fundamental issue of resource scarcity. However, sustainability involves reconciling mankind's needs with the capabilities of the planet; and the key to this approach is ensuring that consumption does not out strip the ability of the planet to replenish its resources. Therefore whilst improving efficiency is important to maximise resource use and minimise wastage, it is reducing consumption that provides the ultimate solution to the sustainability challenge.

Influencing consumer behaviour is a difficult undertaking and there are a number of strategies that can be employed. Consumer education and awareness campaigns that instil the notion of water being a valuable commodity at the consumer level are central to this approach. School education programs, websites, advertising through a range of media, press releases, and WDM discussion forums are just some of the approaches that can be used. On the other hand, it is difficult to measure the impact of awareness campaigns and subsequently challenging to identify the optimal capital investment into such projects. It is also important to invest in these projects over the long term, keeping the campaign interesting so as to continuously influence consumer behaviour.

13.5 Reducing demand for potable water supplies

This WDM objective refers to the need to source alternative water supply options to supplement or replace potable water supplies. One of the central themes of the WSUD concept is the idea that cities should be considered as water supply catchments that have a wide range of water sources available within the urban boundary. Naturally the quality of these water sources may not match that of water sourced from natural catchments through conventional methods, however these sources are a valuable resource and given their proximity to potential consumers, these alternative sources need to be exploited where possible. One of the central themes to the WSUD concept is the 'fit for purpose' approach. Not all domestic water consumption requires potable water; toilet flushing and garden irrigation are two examples of activities that do not require high quality potable water. The goal of water re-use is to substitute potable water with alternative sources of water where the use is fit for the required purpose (Landcom, 2004a). Table 13.2 illustrates some fit-for purpose uses for different water sources.

The suitability of the various alternative water sources have been evaluated with regard to their appropriateness for domestic use. In Table 13.2, a score of 1 represents the ideal use for the water source and a score of 4 indicates that the water source cannot be used for that particular use. The 'fit for purpose' approach often requires some sort of infrastructural investment to facilitate a second non potable water supply; this system is known as dual reticulation. Non potable water can be distributed through a 'third pipe system' in addition to the piped water supply and wastewater systems (BMT WBM, 2009). These systems are developed on a regional scale and can incorporate all of the above alternative water sources to be used on a fit-for- purpose basis (*ibid*). It must be noted however that it is difficult to retrofit a third (and further) reticulation system in a dense urban environment and these systems are most appropriate for greenfield sites or the less dense suburbs. Where these systems are unavailable, water re-use can be restricted to the separation of greywater from blackwater (Landcom, 2004b). This is because blackwater requires treatment at a sewage treatment plant and would thus require a mechanism to redistribute the recycled water for re-use.

Table 13.2: Compatibility of various water sources and appropriate uses
(Landcom, 2004b)

Water source	Uses							
	Garden	Kitchen		Laundry		Toilet	Bathroom	
		Hot	Cold	Hot	Cold		Hot	Cold
Potable	3	2	1	2	1	3	2	1
Wastewater								
Treated black	1	4	4	4	4	1	4	4
Greywater	2	4	4	4	4	2	4	4
Stormwater								
Roof	2	1	2	1	1	2	1	2
Non-roof	2	4	4	4	4	2	4	4

1: Preferred use; 2: Compatible use; 3: Non-preferred use; 4: Not compatible.

Dual reticulation systems are vital to promoting future opportunities for water recycling. Wong & Brown (2008) note that dual reticulation systems are often disregarded for three major reasons. Firstly there often appears to be a lack of cheap alternative water supplies when compared to potable water; however this may be a result of cost analyses focusing on the current costs of water treatment and recycling without recognising recent significant improvements in technology. Secondly, alternative water supplies – such as stormwater – are often seen as unreliable; and thirdly there is the fear of cross-connections leading to a public health issue.

13.5.1 Rainwater & stormwater harvesting

As discussed in Section 10.2.6, rainwater and stormwater harvesting present significant potential as an alternative water supply within urban areas. Based on a 'fit for purpose' approach and the quality of the water collected, the water could be used for garden irrigation, toilet flushing, hot water systems and washing machines (City of Melbourne, 2009).

There is a distinction to be made between rainwater harvesting and stormwater harvesting. Rainwater harvesting usually refers to precipitation that is captured from building roofs; this water is usually considerably less polluted than the water retained from stormwater harvesting. Stormwater harvesting refers to the capture of runoff on a larger scale, from ground surfaces such as roads and car parks and generally involves much larger infrastructure to deal with the greater volumes of runoff.

Rainwater harvesting is a crucial aspect of WSUD; runoff from building rooftops constitutes a large proportion of total runoff from urban areas and capturing this water will reduce urban runoff volumes as well as the frequency of flood occurrences. Environmental benefits include the protection of waterways through reduced runoff volumes, as well as reducing pollutant levels entering receiving waterways (McAlister, 2007). Rainwater is usually captured in tanks which help to trap pollutants such as suspended solids and allow them to settle before use. The tanks can alternatively be fitted with a 'first flush' bypass device to prevent pollutants transported by the first flush of rain from entering the tank.

Stormwater harvesting of surface runoff is similar to rainwater harvesting however it deals with much larger volumes of runoff. Owing to the large volumes, surface storage in ponds or alternatively making use of existing aquifers is usual. Surface runoff may also require additional treatment, although the level of treatment is usually far less than other alternative sources such as wastewater (City of Melbourne, 2009).

13.5.2 Managed Aquifer Recharge as part of sustainable water supply

As described in Sections 10.2.3.3 and 12.2.3, MAR is the process of introducing treated, untreated, or reclaimed water to recharge underground aquifers through pumping, gravity feed, or natural infiltration. The water can then be extracted from the aquifer for re-use at a later stage (Sheng, 2005). MAR can also provide a useful water treatment function and there is significant potential for the indirect re-use of stormwater or reclaimed water through various MAR systems (Dillon, 2005) – although there is also the possibility of negative impacts (quality and quantity / capacity) on the aquifer. One of the critical concerns is thus to ensure that the water used to recharge the aquifer does not contribute to the deterioration of groundwater quality or aquifer properties (McAlister, 2007). The quality of the water prior to injection or infiltration depends on the current state of the groundwater as well as its intended use. Water quality could be improved by incorporating pre-treatment mechanisms such as constructed wetlands, detention ponds, or storage tanks, all or part of which remove pollutants and temporarily store water (BMT WBM, 2009). As noted in Section 12.8 also, it is important that expert opinion is sought on any groundwater infiltration scheme.

The feasibility of MAR schemes is dependent on a number of factors including the hydrological and geological characteristics, the scale required, and the intended use of the groundwater. MAR has great potential as a low cost alternative to surface storage systems and presents a useful solution to the storage of large volumes of stormwater runoff from urban areas.

13.6 Sustainable water supply as a component of WSUD

South Africa is a water-scarce country and water management strategies which attempt to make use of the available water resources in the most efficient and effective manner are required to ensure that the water demands are balanced with available supplies and the negative impacts on sustainable growth are minimised. In this context, the concept of 'sustainable water supply' is used to describe the alternative approaches needed to secure RSA's water resource requirements and contribute to water sensitive settlements. Sustainable water supply can be defined as the use of water in a manner that does not deplete or permanently damage the resource. Sustainable water supply strategies aim to achieve this by: reducing potable water demand through implementing a range of Water Conservation and Water Demand Management (WC and WDM) measures; and maximising the use of alternative water sources such as rainwater, stormwater, wastewater and groundwater in a fit-for-purpose manner.

14. Modelling tools for WSUD

A preliminary identification of the relevant modelling tools for WSUD has been undertaken and is reported here. This information is continuously changing however and therefore the intention is that updated details on specific models and their capabilities will be available through the WSUD website (www.wsud.co.za) on an ongoing basis. It should be noted that the list of models in this section is not prescriptive; it simply serves to provide details of some of the most widely-used in models in this field.

14.1 Integrated urban water management modelling

In order to develop information and data illustrating the benefits of WSUD in the South African context, alternative methods of highlighting the practical, measurable benefits of adopting such an approach are required. One of these alternative methods is the use of modelling to illustrate the impacts of WSUD strategies on urban catchments. There are many numerical models commercially available that deal with the technical components of urban water management but none as yet that include the wider aspects of WSUD – particularly the social and institutional issues that are the biggest obstacle to the development of more sustainable urban water management in South Africa. An extensive review of integrated urban water management (IUWM) models by Breen *et al.* (2006) revealed that the available models generally fail to balance between the scope and detail of an IUWM system. For example, there are models such as *Infoworks* that provide the ability to undertake detailed design, but fail to integrate the three streams of the urban water cycle. Equally, there are a number of models – such as *UVQ*, *Aquacycle* and *Watercress* – that represent the entire water cycle, but do so in a simplistic manner using a system wide water balance (Breen *et al.*, 2006). In response to these findings *eWater* has been at the forefront of developing software tools which may be used to model the urban water cycle and components of it in an integrated manner to include the impacts of alternative water management strategies.

To date there has been a significant focus on modelling one specific part of the urban water cycle – the stormwater system. The development of the sustainable stormwater management discourse has placed a heavy emphasis on water quality (Wong & Eadie, 2000). Typically efforts to improve water quality include the adoption of a source control approach through emission restrictions (Achleitner *et al.*, 2005). However, the complex cause-effect relationships and the variability of water quality means these source control standards do not necessarily improve water quality (Lau *et al.*, 2002; Lijklema, 1995). This has resulted in a transition from 'end-of-pipe' design interventions to approaches that focus on the ambient water quality within a catchment context (Achleitner *et al.*, 2005). Computer based models are useful tools to establish the effectiveness of stormwater management techniques and the degree to which they conform to water quality requirements (Zoppou, 2001).

While a number of models have been developed which represent the total urban water cycle, most of these models are simplistic water balance models. Many cannot simulate both the water quantity and the water quality of an integrated urban water management system (Fagan *et al*., 2010), and few can track waterborne contaminants. Even fewer can simulate the effects of the use of alternative water sources on the urban water cycle and on contaminant flows (Mitchell & Diaper, 2005). Urban water cycle models should at least be capable of simulating flows and their pollutant characteristics over porous and non-porous surfaces as well as through channelled and piped networks (Zoppou, 2001). They should model the hydrological aspects (such as rainfall, infiltration, overland flows and evaporation), as well as the hydraulic aspects (pipe and channel flow) of urban environments (Siriwardene & Perera, 2006).

Despite the limitations of some computer models, they allow the simulation and evaluation of the environmental impact of various design and operational scenarios without the need for costly and time consuming physical testing (Butler & Schultz, 2005). However, computer modelling requires expertise and experience as well as input data that are appropriate and relevant. The process requires calibration and verification of the chosen parameters in order to produce useful results (Butler & Schultz, 2005). The reliability of the models also depends on the accuracy of the parameters chosen for the catchment to be investigated (Siriwardene & Perera, 2006).

14.2 Identification and selection of models

This report reviews the models that have been identified as being appropriate for use in WSUD modelling for South Africa. A comprehensive search was undertaken to uncover all relevant IUWM / WSUD models that are currently available. This primarily took the form of an internet search for models using relevant key words and a review of literature that presented or compared different models. A list of all the models identified was compiled, and a further internet-based search was undertaken to determine whether the software was still available and compatible with current operating systems. Mitchell *et al.* (2007), Elliott & Trowsdale (2007), Zoppou (2001) and Last (2010) all provided extensive background information on what models were available. The search identified a total of 98 models of which 63 are still currently in use. These 63 models were then considered for further review with a view to identifying those which are currently available and may be of use to interested stakeholders in South Africa. In many instances the only available information was either from the individual model's 'User Manual' or from a subjective opinion based on personal experience. The final selection of models was thus based on the following criteria:

- Available model support.
- Ability of the software to model integrated urban water management / sustainable urban drainage systems / water sensitive urban design.
- Model capabilities.
- Cost.

It should be noted that the selection of models for review as part of this report does not exclude the use of any of the other models identified.

14.3 Stormwater models

There is a wide range of stormwater models available. The purpose, spatial and temporal scale, cost, usability and data requirements for each model vary. The following section provides a brief overview of a selection of stormwater models which are seen as appropriate for South Africa.

14.3.1 *MUSIC*

The Model for Urban Stormwater Improvement Conceptualisation (*MUSIC*) is a stormwater quality assessment tool developed by the Australian water management company, eWater. The model is used to analyse the conceptual designs of stormwater infrastructure and places particular emphasis on water quality objectives (Elliott & Trowsdale, 2007). *MUSIC* models downstream flow control and water quality benefits achieved through the installation of structural Best Management Practices (BMPs) (Lloyd *et al.*, 2002). First developed in 2001, the software is designed to help urban stormwater professionals create and visualise strategies to tackle problems associated with stormwater hydrology and pollution impacts (eWater, 2011a). *MUSIC* can operate over a range of spatial and temporal scales; it can simulate catchments of 0.01 to 100km^2 with time steps ranging from 6 minutes to 24 hours. The basic operations of the software model include: (Lloyd *et al*., 2002)

- Determining the probable water quality being released from urban catchments.
- Predicting the performance of structural BMPs in protecting water quality.
- Designing an integrated stormwater management system.
- Evaluating the success of potential designs against a range of water quality standards.

MUSIC enables designers to model both the stormwater quantity and quality characteristics of stormwater systems for catchments of varying size. The program incorporates a range of treatment measures either individually, within a treatment train, or as distributed treatment measures (Singh *et al*., 2008). It helps decision makers in the planning and design phases by simulating the stormwater quality performance of different conceptual designs (eWater, 2011a).

MUSIC is a useful tool with which to link government policy regarding water quality standards to stormwater quality technology (Lloyd *et al*., 2002). This is illustrated in a case study of Redland City Council in Australia that used it to evaluate the designs submitted with development applications (eWater, 2011b). The model allowed authorities to quickly check the adequacy of designs in meeting the required standards, thereby saving time for both the authorities and the developers (eWater, 2011b).

The latest version of *MUSIC*, i.e. *MUSIC 5.1* was released in July 2012. One of the major advancements within *MUSIC 5.1* is the ability to better model stormwater harvesting and re-use. It is possible to specify a re-use demand and model how well this can be met.

14.3.2 *SLAMM*

The Source Loading And Management Model (*SLAMM*) is a planning level tool aimed at predicting flow and pollutant discharges from a broad range of development scenarios with many different combinations of stormwater controls (PV & Associates, 2011a). It is capable of calculating mass balances for dissolved and particulate pollutants for different development scenarios and rainfall events (Pitt & Voorhees, 2002). The program was initially developed in the 1970's to model the interactions between sources of urban runoff pollution and water quality. Since then the software has been expanded to include a range of source area and outfall control measures such as infiltration devices, detention ponds, porous pavement and swales (PV & Associates, 2011b).

SLAMM is based on actual field observations with limited reliance on purely theoretical concepts that have not been confirmed or documented in the field (Pitt & Voorhees, 2002). It places special emphasis on small storm hydrology, as the vast majority of stormwater quality issues are associated with smaller rainfall events (PV & Associates, 2011b). In order to model these events more accurately, *SLAMM* includes unique process descriptions which allow a more accurate prediction of flows and pollutant loads for a given rainfall event (Pitt & Voorhees, 2002, PV & Associates, 2011a).

SLAMM is currently undergoing an extensive overhaul prior to it being re-released; further details on this program will therefore only be provided once the new version has undergone its testing phase and the results have been published.

14.3.3 *SUSTAIN*

The System for Urban Stormwater Treatment and Analysis INtegration (*SUSTAIN*) was developed as a GIS-based decision support tool by Tetra Tech in conjunction with the Environmental Protection Agency (EPA). The EPA report on the *SUSTAIN* model (Shoemaker *et al.*, 2009) provides an overview of the model and its capabilities.

SUSTAIN is a tool capable of performing a comprehensive analysis of stormwater management strategies at multiple scales. It helps to evaluate, select and place structural BMPs within a given catchment on the basis of user-defined cost and effectiveness criteria. It provides a mechanism that enables the evaluation of the most appropriate location, type and cost of stormwater BMP's to achieve specified water quality goals. It was developed by combining publically available modelling techniques, management costs and optimisation tools within a geographic framework.

SUSTAIN is only compatible with ArcGIS 9.3.1 and Windows XP. As a result it is now out of date and not compatible with many modern machines. The USEPA currently has no plans to upgrade the software in the near future (Selvakumar, 2012).

14.3.4 *SWMM*

The Storm Water Management Model (*SWMM*) was first developed by the Environmental Protection Agency (EPA) in 1971 and has had several major overhauls over the years (Rossman, 2008). The *SWMM User's Manual* (Rossman, 2008) provides a useful overview of the model which is summarised as follows.

SWMM is a software package that enables dynamic rainfall-runoff modelling, and can be used to model long term or single rainfall events. The model simulates the quantity and quality of runoff that emanates from an urban environment. The model consists of two major components, i.e. runoff and routing. The runoff component produces runoff and pollutant load simulations for a number of sub-catchments. The routing component simulates the transportation of runoff through stormwater infrastructure such as pipes, channels, storage and treatment devices (SuDS / BMP's), pumps, and regulators. *SWMM 5* (the latest version) has the capability of evaluating the effectiveness of BMPs. It tracks both water quantity and quality in each designated sub-catchment, as well as the flow rate, flow depth and quality of water at multiple time steps during the simulation. It is easier to operate and more accessible to the current generation of engineers and water specialists than the previous versions, however the models are still too complex to be used by non-modelling planners (Elliott & Trowsdale, 2007; Gironás *et al.*, 2010). *SWMM* may also be linked to other models, for example Rowan (2001) linked *SWMM* and *MODFLOW* using a 'multiple model broker', which allows for the exchange or feedback of information between the two models at each time step during the modelling process, and Yergeau (2010) coupled *SWMM* and *MODFLOW* models in a study of an urban wetland.

SWMM 5 is not integrated with GIS which requires planners and designers to import and export data between different formats. There are however a range of additional software packages which use *SWMM* as the core processing / calculation software, but then improve the usability of the software through an improved user interface. This includes a GIS interface with the ability to export results into a range of formats not usually available in the USEPA *SWMM 5* package. For example, *PCSWWM*, developed by CHI International greatly improves the usability and functionality of *SWMM*. *PCSWMM 2011* – the latest version of the software which is continuously being updated – incorporates a GIS engine that works with a large number of GIS data formats, and provides tools for streamlining model development, optimisation and analysis for a comprehensive range of applications (CHI, 2012). *PCSWMM* is available free of charge to students and academic institutions, however for commercial firms costs the amounts for the different packages as at 15 November 2013 are shown in Table 14.1.

Table 14.1: Cost of *PCSWMM*

Version	Cost in US $ per annum	Cost in ZAR per annum ($1 = ZAR 10.2 at 15 November 2013)
Single User – *PCSWMM* Pro License	$1 440.00	R14 688.00
Single User – *PCSWMM* Pro 2D Licence	$2 160.00	R22 032.00
Enterprise Licence – per user	$480.00	R4 896.00
Enterprise Licence – Professional License once off per annum	$4 000.00	R40 800.00

Similarly, *XPSWMM*, developed by XP Solutions, uses elements of *EPA SWMM* to provide a proprietary hydrology / hydraulics model that is able to model stormwater systems in a similar manner to *EPA SWMM* / *PC SWMM* (XP Solutions, 2012).

14.3.5 Comparison of stormwater models

Tables 14.23 and 14.3 provide comparisons of the various stormwater models and their capabilities, both from a design criteria perspective as well as their usefulness in addressing the modelling of specific SuDS components.

Table 14.2: Potential models for design criteria computation (after Elliot & Trowsdale, 2005)

	Public Education	**Research**	**Developing Sizing rules for devices**	**Planning of land use in catchments/cities**	**Preliminary design of regional controls**	**Preliminary design of a subdivision or site**	**Detailed design of regional drainage system**	**Detailed design of subdivision or site**	**Site Layout and materials selection**
MOUSE		Suitable	Suitable	Suitable	Suitable	Suitable	Marginal	Marginal	Marginal
MUSIC			Suitable	Suitable	Suitable	Suitable			
P8			Suitable	Suitable	Suitable	Marginal			
SLAMM			Suitable	Suitable	Suitable	Marginal			
StormTac				Suitable	Suitable				
SWMM		Suitable	Suitable	Suitable	Suitable	Suitable	Marginal	Marginal	Marginal
PCSWMM		Suitable	Suitable	Suitable	Suitable	Suitable	Marginal	Marginal	Marginal
UVQ		Suitable	Marginal	Marginal	Marginal	Suitable			
WinDes (Quant. only)			Marginal		Suitable	Suitable	Suitable	Suitable	Marginal

Key	(black)	**Model is suitable for use**	(grey)	**Model is marginally suited for use**	(white)	**Model is not suited for use**

Table 14.3: SuDS component capabilities for selected design models (after Elliot & Trowsdale, 2005)

	Imperviousness reduction	Ponds and wetlands	Soil protection	Reduction of contaminant generation	Infiltration trenches/bores	On-site detention tanks	Swales	Run on	Rain tanks	Bioretention, rain gardens filtration devices	Permeable paving	Green roofs
MOUSE	■	■	░	░	░	■	■		░	░	░	
MUSIC	■	■	░	░	■	■	■	░	■	■	░	░
P8	■	■	░	░	■	■	■		░			
WinSLAMM	■	■	░	░	■		■			■		
StormTac	■	■	░	░			■					
SWMM	■	■	░	░	░	■	■	■	■	■	■	■
UVQ	■	■	░	░	■	░		■	■	░		
WinDes (Quant. only)	■	░			░	░	░		░	░	░	░

Key

■	**Model explicitly addresses the use of the device or approach**
░	**Model may be used for the approach**
(blank)	**Cannot be used for device or approach**

14.4 Water cycle models

14.4.1 *Source Urban*

Source Urban is a specific function within the water cycle model *Source*, that has been made publically available through membership into the Source Modelling Community (Feilin, 2012). It is designed to represent a wide variety of water sources such as (eWater, 2012):

- River extractions to in-line or off-line reservoirs.
- Direct river extractions.
- Groundwater extractions.
- Alternative sources such as stormwater harvesting and wastewater treatment.
- Desalination.
- Decentralised sources such as rainwater tanks.

"*In addition to accounting for alternative water sources in the urban environment, Source can also represent urban demand. Satisfying urban demand is the aim of urban water resources managers and this topic has received a large amount of attention and there are, a large number of existing urban demand models. Source does not seek to replace these models; rather it provides a framework in which existing demand models are incorporated through importing existing time series, mathematical expressions or plug-ins. This flexible framework ensures compatibility with existing demand model allowing continuity of data and modelling approached* (eWater, 2012)". The cost of *Source* varies depending on the size of the company or institution, as determined by the company's annual turnover.

Table 14.4: Cost of *Source Urban*

Annual turnover / nature of organisation	Cost of *Source* in AUD (unlimited installations)
Organisations with annual income of greater than AUD $50 million	$50 000 pa
Organisations with annual income of AUD $10-50 million	$25 000 pa
Organisations with annual income of AUD $2-10 million, and all universities and government-funded research organisations	$10 000 pa
Organisations with annual income of less than AUD $2 million	$5 000 pa

14.4.2 *UVQ*

UVQ (Urban Volume and Quality) was developed to provide a means for rapidly assessing conventional and non-conventional approaches to providing water supply, stormwater and wastewater services to urban allotments, neighbourhoods and study areas. It is an effective preliminary assessment tool for determining the impacts of urban development options on the total water cycle, as well as the performance of a wide range of non-conventional demand and supply side management techniques (Mitchell & Diaper, 2005).

UVQ is the successor of *Aquacycle* (Last, 2010; Mitchell & Diaper, 2005). The main improvements were that it added a contaminant balance to the water balance, and there has been an improvement in the user interface (Last, 2010; Mitchell *et al.*, 2007). According to Last (2010), the main strengths of *UVQ* include: simplicity, rapid runtime and description of the cityscape. Weaknesses include the predominant focus on residential areas, range of indicator outputs, limited availability of water management techniques, and limited consideration of the natural systems.

Mitchell & Diaper (2005) highlight the fact that *UVQ* was developed "*with the objective of maximum applicability to all urban areas in both Australia and Europe*". They note that *UVQ* can model a variety of land use types (not just residential); a range of different conventional water infrastructure technologies and account for local climatic conditions. Mitchell *et al.* (2007) do however recognise that the one disadvantage of *UVQ* is that it can only handle one climate file, which then assumes a constant climate for the whole model.

UVQ represents the catchment using three spatial scales, i.e. site / unit block, local / neighbourhood, and regional / catchment (Elliott & Trowsdale, 2007; Mitchell & Diaper, 2005). This allows for a range of scales and different water management technologies and approaches to be modelled (Elliott & Trowsdale, 2007). It is a volumetrically-based water balance model that can be used for modelling integrated urban water management strategies. It is relatively simple to use, and is freely downloadable. While more complex programs are now available, *UVQ* can still be used for modelling the urban water cycle.

14.4.3 *Urban Developer*

Urban Developer is a model created by the company, eWater. The model was developed in response to a comment that "*to date, no single model offers the ability to undertake the integrated modelling required to assess the performance of integrated urban water management options across the entire urban water cycle*" (Hardy & McArthur, 2011).

Urban Developer has been developed as "*a flexible and modular modelling environment for the simulation of urban water cycle services systems*" (Snowdon *et al.*, 2011). It simulates the water supply, stormwater, and wastewater systems at a range of spatial and temporal scales within a single framework to improve the understanding of the potential of integrated urban water management (Snowdon *et al.*, 2011). The key features of *Urban Developer* are described by Hardy & McArthur (2011) as follows:

- An easy-to-use node-link modelling environment that includes representation of all three urban water cycle service networks: water supply, stormwater, and wastewater.

- Simulation of sub-daily demand and end-use to improve insights into the operation and interactions of water cycle service systems in integrated management frameworks.
- The capability to model using continuous rainfall and climate data as well as supporting AR&R Design Rainfall based assessment of stormwater system components.
- The ability to simulate at temporal and spatial scales commensurate with state and local government planning and approval metrics. For example, *Urban Developer* can support the estimation of peak discharge and the evaluation of measures to achieve mandated peak discharge reduction targets.
- The ability to group service network elements into sub-networks, reducing the visual complexity of models and allowing the *Urban Developer* software to be more easily applied at a range of scales.
- Reduced network and computational complexity by using styles: ‘sets’ of configuration parameters that can be re-used and applied to multiple node models.

Urban Developer considers all elements of the urban water cycle (stormwater, wastewater and potable water) and assists in considering potential management strategies including re-use, alternative supply options and water efficient appliances (Feilin, 2012). It is a useful tool for assisting in the conceptual design of a development. The software is able to analyse the inter-relationships between all the streams of the water cycle and compare conceptual designs against legislative requirements or design targets. The model is being developed on an on-going basis in order to improve its capabilities of assisting stakeholders to understand the costs and benefits of integrated urban water management. It promises to become, if it is not already, the most advanced modelling tool for managing the urban water cycle at a local to regional scale.

14.4.4 *Watercress*

WaterCress (Water Community Resource Evaluation and Simulation System) is a free-to-download model that was developed to analyse the feasibility of conventional and alternative water supply options (Clark *et al.*, 2002; Cresswell *et al.*, 2011; Last, 2010; Mitchell & Diaper, 2005). It is a continuous time series, total water cycle model, which simulates the passage of flows through natural and constructed water systems. The model provides statistics on the flows and storages within the water system over the period of modelling, thus providing information on the performance of the system against desired outcomes or against alternative system layouts. It works on similar principles to *Aquacycle* / *UQV* and analyses the movement of water volumetrically (Last, 2010; Mitchell *et al.*, 2007). *WaterCress* is more flexible and may be used up to river basin scale (Last, 2010). This allows the model to consider the whole catchment and better represent a catchment’s boundary conditions. *WaterCress*’s indicators in this regard are (Last, 2010):

- Reliability of water supply.
- Water quality.
- Average cost.

14.4.5 *WEAP*

The Stockholm Environment Institute (SEI) developed the Water Evaluation And Planning system, *WEAP* (Mitchell *et al.*, 2007; Rodrigo *et al.*, 2012; Sieber & Purkey, 2011). *WEAP* is a "*GIS-based tool for integrated water resources planning that operates on the basic principle of water balance accounting"* (Mitchell *et al.*, 2007).

WEAP operates as a water balance model and can be used to model systems from municipal to agricultural and single sub-basins to complex river systems (Sieber & Purkey, 2011). *WEAP* is capable of modelling the implementation of the full range of WSUD technologies. A recent study for the USEPA demonstrated its applicability in a study entitled 'Total Water Management' (Rodrigo *et al.*, 2012). Rodrigo *et al.* (2012) used *WEAP* to model the city of Los Angeles, USA and demonstrated the benefits of a total water management approach. It has a range of capabilities and can address a wide range of issues including "*sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and streamflow simulations, reservoir operations, hydropower generation and energy demands, pollution tracking, ecosystem requirements, and project benefit-cost analyses*" (Sieber & Purkey, 2011).

14.4.6 *AISUWRS DSS*

The *AISUWRS DSS* was developed as part of a project entitled "Assessing and Improving Sustainability of Urban Water Resource Systems" (Wolf *et al*., 2006). The *AISUWRS DSS* links a number of models to account for the fluxes of water and contaminants between the surface, subsurface and groundwater.

The *AISUWRS DSS* incorporates an urban water balance model, *UVQ* (Section 14.4.2) and subsurface models, such as the Network Exfiltration and Infiltration MOdel (*NEIMO*), Sewer Leak Index (*SLeakI*) and Public Open Space Index (*POSI*) and in the final stage groundwater flow modelling is performed using either *MODFLOW* or *FEFLOW* (Section 14.6) Figure 14.1 shows the conceptual linkages of the components of *AISUWRS DSS*. While there are a number of other DSS models available only the *AISUWRS DSS* has been specifically applied in urban groundwater studies.

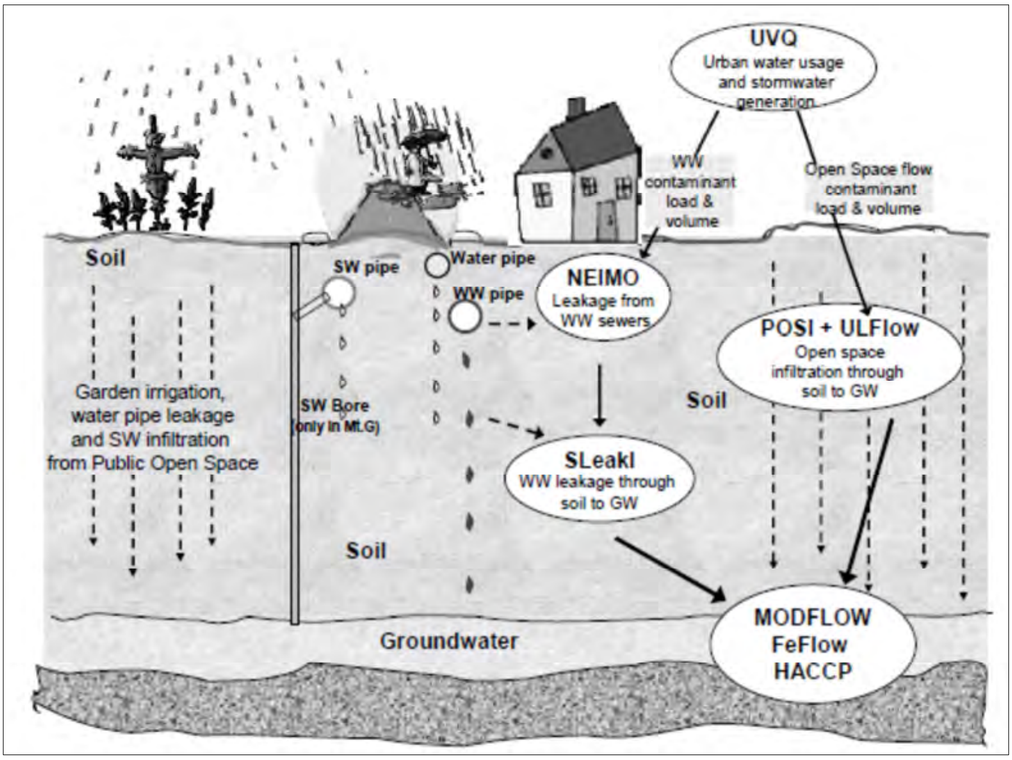


Figure 14.1: Conceptual linkages of components of *AISUWRS DSS* (Wolf *et al*., 2006)

14.4.7 *MIKE Urban*

MIKE Urban is a software package developed by DHI, and based on SWMM 5.0. It covers the whole water cycle, including water distribution, stormwater collection, sewage collection, and groundwater processes. It also allows for the modelling of WSUD devices that are used to manage urban water. It is fully integrated with ArcGIS for improved interfacing. Figure 14.2 provides an overview of the *MIKE Urban* model, highlighting its core modelling processes. The cost of *MIKE Urban* and other DHI products is dependent on the spatial scale and detail of the modelling capabilities required. The software is relatively expensive to commercial users but it is available under agreement at no cost to educational institutions in South Africa. Information on model applications and further literature is available on the DHI website (DHI, 2011). Other products in the *MIKE* suite of hydrological models include *MIKE SHE* and *MIKE FLOOD*. An important component for the hydrological modelling of urban areas is the ability to represent the complete urban water system; *MIKE SHE* therefore has the ability to be coupled with *MIKE URBAN*.

MIKE SHE was developed in 1969 by Freeze & Harlan (1969) who described the physical processes of the hydrological cycle by their governing partial differential equations (Graham & Butts, 2005; Zhao, 2012). From 1977 further development of the work by Freeze & Harlan (1969) resulted in Système Hydrologique Européen (*SHE*) and finally *MIKE SHE*. Since the mid 1980's the DHI Water & Environment department has continued with the development of the *MIKE SHE* model (Graham & Butts, 2005).

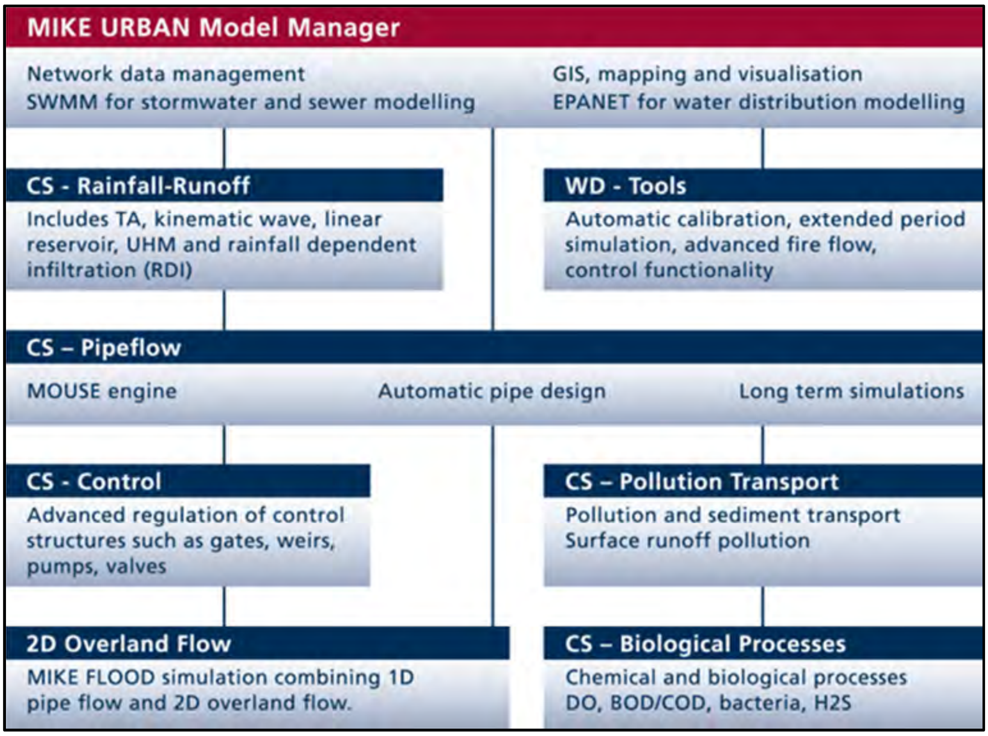


Figure 14.2: Overview of *MIKE Urban*

MIKE SHE is a physically-based, fully-integrated surface and groundwater hydrological model. It represents the space as a grid and can function at a range of spatial scales, from a single soil profile to a system consisting of a number of large catchments (>80 000km^2). It is a flexible modelling system that allows the user to develop an appropriate model within it that is in line with the user's conceptual model, available data, desired outcomes and the required detail and complexity (Graham & Butts, 2005). There are a number of limitations to the physically-based approach that forms the basis of *MIKE SHE*, *viz*.:

- The high cost and difficulty of data acquisition.
- The higher computer processing requirements and simulation run time.
- The over parameterisation of relatively simple or unimportant model processes may lead to an unnecessarily complex model.
- The disparity between the experimental scale and the scale of the grid used by MIKE SHE.

MIKE SHE can represent a number of surface water processes such as evaporation, overland flow and channel flow, whilst also simulating subsurface hydrological processes such unsaturated flow and saturated groundwater flow. Another important aspect is its ability to represent the complete urban water system through coupling with *MIKE URBAN* which allows for the hydrological components that are specific to the urban context to be calculated such as the flow of water in sewerage and stormwater pipes. *MIKE URBAN* also allows for the modelling of WSUD devices that are used to manage urban water.

14.4.8 Innovyze software suite

In 2009 two hydraulic modelling companies, MWH Soft and Wallingford Software merged. The company now known as Innovyze offers a wide range of software options covering the full urban water cycle including tools for active monitoring and management as shown in Table 14.5 (Innovyze, 2012). It is not possible to review each of the software packages independently, however a product catalogue is available online which provides the advantages and disadvantages of each package. A range of interesting case studies and published research may be accessed online for a more in-depth analysis of the capabilities of the different Innovyze software options (Innovyze, 2012).

Table 14.5: Innovyze software suite

Sector	Model
Drainage & flooding	*InfoWorks, ICM InfoWorks, CS InfoWorks SD, InfoSWMM*
	2D Simulation Solutions H2OMAP SWMM
	InfoSewer
	H2OMAP Sewer InfoWorks RS
	FloodWorks
Asset performance modelling	*ACAM*
	InfoMaster InfoNet
	InfoNet Mobile CapPlan Water CapPlan Sewer
Water supply	*InfoWorks WS InfoWater*
	InfoWater MSX InfoWater UDF IWLive
	H2 H2
	OMAP Water ONET
	Surge Solutions

14.5 Comparison of water cycle models

Table 14.6 provides an overview of selected models that may be used to model the whole water cycle and gives an overview of the capabilities, costs (2012 values), as well as the strengths and weaknesses of these models. A useful review of integrated urban water modelling tools (with more detailed information) is also available in the paper by Bach *et al*., 2014.

Table 14.6: Comparison of water cycle models (Last, 2010; Mitchell & Diaper, 2005)

Model	**Developer**	**Cost (ZAR – 2012 values)**	**Capabilities**				**Strength**	**Weakness**
			Scale	**Time step**	**Data requirements & availability**	**Type**		
Infoworks	Infoworks	n.a.	Catchment		Requires a large amount of data	Detailed design	Detailed and accurate modelling	Either models supply, collection or river networks. Limited integration
Source Urban	eWater	R 50 500- R 500 000						
UQV / AquaCycle	CSIRO	Free	Multiple urban catchments	Daily	Limited data required	Scoping tool	Easy to use, contaminant balance	Does not consider energy requirements. Limited consideration of natural systems. No economic analysis.
Urban Developer	eWater	R32 500						
Watercress	Water Select	Free	Multiple Catchments	Daily	Requires a large amount of data	Screening tool for alternative water management strategies	Range of indicators. Considers natural systems	Additional complexity of modelling at river catchment scale. No consideration of energy use. No support

14.6 Urban groundwater modelling

Groundwater modelling in urban areas is necessary for a number of reasons (Vázquez-Suñé *et al.,* 2006):

- Combining old and new information for aquifer characterisation and status.
- Improving the understanding of groundwater mass balance.
- Assessing groundwater related environmental impacts.
- Testing groundwater-related plans and policies.
- Assisting in the design and development of groundwater rehabilitation measures.

The monitoring of groundwater levels and the characterisation of soil and geological properties, as described earlier in Section 12.7, is important for the analysis of groundwater characterisation and status, but monitoring data is generally limited to point measurements and transect profiles and does not account for the variability between these points of measurement. The information acquired from the data collection can be used to calibrate and validate physically-based models. The calibration of a model requires actual measures of aquifer characteristics to help estimate various model parameters. The model's simulated results can then be validated by comparing actual measurements, to test and improve the models performance (Friedel, 2006). Modelling also allows for the testing of different scenarios which provides an inexpensive and practical means of determining the sensitivity of a catchment's hydrological and hydrogeological responses under different management and design scenarios. Models also play a crucial role in decision support by allows a number of management and planning decisions to be tested before implementation; this has significant benefits in terms of environment and social protection, as well as reducing costs and improving the success of projects (Schulze, 2004). Modelling the urban hydrological system will aid the decision making possess in WSUD through the ability to simulate the hydrological and hydrogeological conditions and test a variety of WSUD scenarios.

Urban groundwater modelling is complex as it is dependent on both surface and subsurface hydrological processes. Surface water, urban infrastructure, soil characteristics and pipe leakages all determine the amount and rate of groundwater recharge, flow and storage. Linking standalone models that represent the surface and subsurface components separately of the urban hydrological cycle is the most common method of modelling urban groundwater. This method has been used to develop decision support systems (DSSs) as shown in studies by Wolf *et al.* (2006), Droubi *et al.* (2008) and Kalbacher *et al*., (2012). Wolf *et al*. (2006), as part of a project entitled "Assessing and Improving Sustainability of Urban Water Resource Systems" (AISUWRS), linked a number of models to account for the fluxes of water and contaminants between surface, subsurface and groundwater. The AISUWRS DSS incorporates an urban water balance model, Urban Volume and Quality (*UVQ*) and subsurface models, such as the Network Exfiltration and Infiltration MOdel (*NEIMO*), Sewer Leak Index (*SLeakI*) and

Public Open Space Index (*POSI*) in the final stage whereby groundwater flow modelling is performed using either *MODFLOW* or *FEFLOW*. Droubi *et al*., (2008) dynamically linked the water evaluation and planning (*WEAP*) software and the groundwater flow model *MODFLOW*. Other examples include Kalbacher *et al*., (2012) where a number of different model combinations were used, such as the mesoscale hydrologic model (mHM), the EPA Storm Water Management Model (*SWMM*), aRoot and the Biogeochemical Reaction Network Simulator (*BRNS*). These model combinations are all linked to the unsaturated and saturated subsurface model, OpenGeoSys (*OGS*). This DSS is known as the IWAS-Toolbox. Additionally, simpler applications of SWMM have been demonstrated by Rowan (2001) and Yergeau (2010). Rowan (2001) linked *SWMM* and *MODFLOW* using a 'multiple model broker', which allows for the exchange or feedback of information between the two models at each time-step during the modelling process and Yergeau (2010) coupled the *SWMM* and *MODFLOW* models in a study of an urban wetland. Göbel *et al*. (2004) used the *GwNeu* Model to calculate the recharge for the North Rhine-Westphalia in Germany (excluding infiltration devices) and the recharge from infiltration devices was modelled using *HYDRUS 2D/3D*. The calculated recharge from both these models could then be used as input for the numerical groundwater model, *SPRING*. Many of the applications of the DSSs have not been applied extensively and only the AISUWRS DSS has been specifically applied in urban groundwater studies.

Most of the popular groundwater flow models such as *MODFLOW* and *FEFLOW* are three dimensional, finite difference groundwater models that solve a combination of Darcy's law for water flow in saturated media and a mass balance equation for various points in the study area. The study area in these models is represented as a matrix of cells, and within each cell is a 'node'. The combination of equations is solved in each of these nodes and the cell-to-cell flow can therefore be derived. *MODFLOW* is a good example of a three dimensional, finite difference groundwater flow model as it is one of the most well applied, tested and supported groundwater models available and is recognised as an industry standard for groundwater modelling (Yan & Smith, 1994; Camp Dresser & McKee Inc., 2001; Rowan, 2001; Kumar, 2002; Droubi *et al*., 2008; Yergeau, 2010; Boskidis *et al*., 2012). As previously described, *MODFLOW* has been applied in a number of other applications in urban areas through the coupling of urban stormwater models and it has a number of surface water-groundwater packages that can be applied to measure the interactions between surface water and groundwater; however, Brunner *et al*. (2009) suggests that the software has a number of limitations when dealing with surface-groundwater interactions – which are an important component in WSUD studies. The first limitation is that the unsaturated zone is not considered in flow interactions between rivers and groundwater. Second, there is often a mismatch between the river width and cell size as the river is assigned to a particular cell which is often much wider than the river. Third, because the river is tied to a particular cell, it cannot be discretised horizontally. Fourth, because vertical discretisation is used to prevent drying out of the cells this can lead to errors in water table simulations.

Given the limitations associated with current urban water management models (e.g. *SWMM*, *MOUSE*, *P8* or *MUSIC*) that have limited groundwater modelling capabilities as outlined in Elliot & Trowsdale (2007) and the limitations experienced through the application of the loosely coupled surface and groundwater models there is a need to for a fully integrated surface water and groundwater modelling tool (Barron *et al*., 2013). There are a number of surface water and groundwater models available, that are fully integrated and spatially distributed, that may be more suitable for modelling surface-groundwater interactions, such as *InHM* (VanderKwaak & Loague, 2001), *MODHMS* (HydroGeoLogic, 2006), HydroGeoSphere, *HGS* (Therrien *et al.*, 2009), *Wash123D* (Cheng *et al.*, 2005) and *ParFlow* (Kollet & Maxwell, 2006). A recent application of *MODHMS* by Barron *et al*. (2013) was used to identify the impact of urbanisation on shallow groundwater in Western Australia. It highlighted the potential for the further application and testing of fully integrated, spatially distributed hydrological models in urban areas.

Another option that is available is *MIKE SHE*, part of the *MIKE* suite of hydrological models developed by DHI Water & Environment (as described in Section 14.4.7). *MIKE SHE* is a fully integrated surface and groundwater model which means that it can represent a number of surface water processes such as evaporation, overland- and channel flow, whilst also capable of simulating subsurface hydrological processes such as unsaturated and saturated groundwater flow.

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Appendix A

International examples of WSUD implementation

(Wu, 2012)

A1 Examples of integrated WSUD implementation

The ultimate goal of WSUD is to integrate all aspects of the urban water cycle. This can be achieved by implementing various measures at a range of scales that deal with certain aspects of the urban water cycle. WSUD has recently shifted away from the stormwater focus. This section presents three case studies that show the integration of all urban water components. The first case study, The Grove Precinct in Australia, is an example of WSUD on a local scale; the second case study, Mawson Lakes, is an example of WSUD at a precinct scale; the third case study, Singapore, presents WSUD on a regional scale, and shows how a city can be more water sensitive. Seoul, a further case study is also discussed to show how water can be used to break down the traditional paradigms in urban development, and how water based landscaping can improve the urban microclimate and be a proponent of economic growth.

A1.1 Australia – Integrated WSUD

A1.1.1 The Grove Precinct, Perth – Local integrated WSUD

The Grove Precinct is a development in the western suburbs in Perth. This development houses a community centre, a library, and the administration offices of the Shire of Peppermint Grove. The outstanding feature of this development is its wide usage of green technology that focuses on energy efficiency, onsite renewable energy generation, climate sensitive architectural design, and integrated water management. The integrated water management system, depicted in Figure A.1, consists of: a wastewater re-use system, a rainwater system, and a stormwater treatment system. This development is a good example of WSUD on a local scale as the holistic management of all components of the water cycle appears to have successfully achieved all the goals of WSUD.

The wastewater re-use system is a decentralised treatment facility that separates wastewater into its three components (greywater, brown water, and yellow water from the urinals), treats them, and then re-uses them for irrigation. It is estimated that the wastewater re-use system will save an estimated 700 kℓ/yr. Greywater is collected from showers and hand basins, and then for treatment and distribution. The treatment system consists of a simple secondary and tertiary treatment process. Secondary treatment occurs in the sedimentation tanks, and tertiary treatment consists of ozonation – a process that utilises ozone as an oxidising agent to eliminate waterborne organisms. Brown water is collected and treated using a Biolytix wastewater treatment system. The Biolytix system is a self-sustaining, chemical-free, biological treatment system that is low on cost and energy. The system treats the wastewater to irrigation standards, and the effluent is distributed for onsite landscape irrigation. Yellow water is collected from waterless urinals, and stored in a series of in-ground tanks. These tanks are cycled in such a way that the yellow water is stored for a minimum of six months. The six months storage period sterilises the yellow water; the nutrient-rich, sterile yellow water is then sent for irrigation in controlled volumes (Josh Byrne & Associates, 2011a).

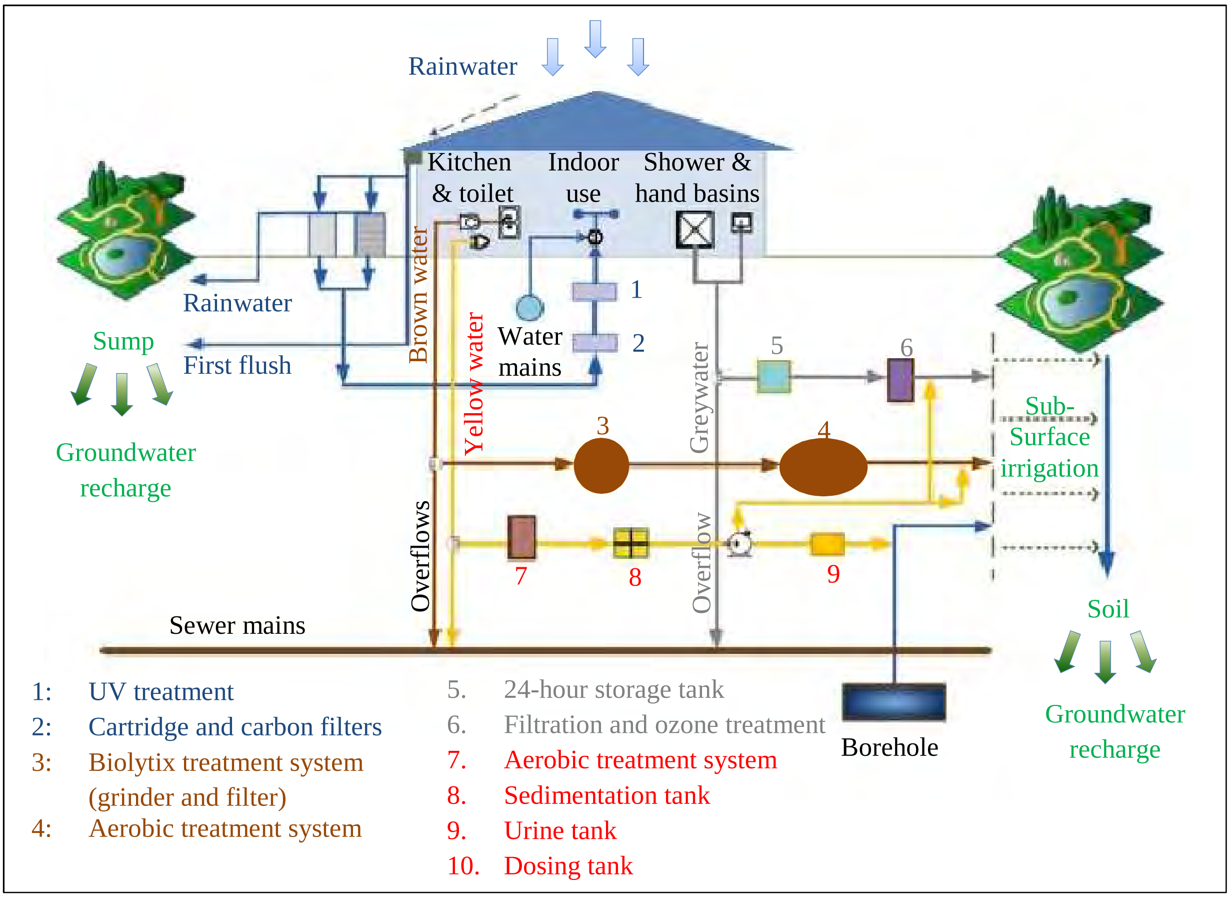


Figure A.1: The Grove Precinct integrated water management system
(adapted from Josh Byrne & Associates, 2010)

The Grove Precinct further reduces potable water demands by using a rainwater harvesting system. It is a sophisticated system that is designed to meet 100% of internal water demands (but does have a backup system connected to the water mains in the case of low rainfall periods). The system consists of rainwater tanks located above or below ground. These tanks collect water from the roof catchment of the building, and have automatic first-flush devices to remove the first few millimetres of rain. The collected water is pumped from the tanks to a treatment facility consisting of microfiltration and UV disinfection. This treatment treats it to potable standards; it is then sent for distribution in the internal potable water network. In addition to these standard facilities, there are two innovative features: real-time water level monitoring and syphon drainage. Metering devices are located on all of the tanks; these meters provide real-time monitoring of water levels. The pipe network in the system is designed to be airtight and is almost constantly filled with water, hence creating a syphon. This design allows self-cleaning operation and thus low-maintenance. This rainwater harvesting system is estimated to save 730 kℓ/yr. of potable water (Josh Byrne & Associates, 2011b).

Stormwater is managed using local SuDS and pre-treatment measures. The development is located on a low-lying area and receives stormwater runoff from a 25 ha catchment. The system is designed for low-flow, normal-flow, and first-flush stormwater runoff. In major storm events, the system treats as much as it can; the overflows are directed to the conventional stormwater system. The system incorporates gross pollutant traps that remove large solid pollutants. The runoff is collected in a 3 000 ℓ concrete tank after passing the pollutant traps, and the stormwater is then pumped to four sedge beds. Sedge beds are similar to reed beds: they are essentially low-lying points of land that obstruct drainage, thus creating waterlogged soils which allow for vegetation growth. The sedge beds have a horizontal subsurface flow layer. The vegetation in the sedge beds treats the stormwater biologically, removing such pollution as nutrients, heavy metals, suspended solids, etc. The stormwater flows through the subsurface layers before being directed to an on-site infiltration basin where it recharges the local aquifer (Josh Byrne & Associates, 2011c).

The developers have implemented a variety of technology to achieve the goals of WSUD. The Grove Precinct is actively promoted by the developers who regularly hold workshops and presentations on the systems in place. These educational and publicity programmes are key aspects of promoting WSUD to increase its adoption in new and existing developments. The project was financed with Australia's Green Precinct Fund which encourages the adoption of water and energy saving measures.

A1.1.2 Mawson Lakes, Adelaide – Precinct integrated WSUD

Mawson Lakes is a small, recently finished suburban development in Adelaide. Lend Lease, the property developers of Mawson Lakes, began developing the suburb in 1998, and finished it in 2012. It currently accommodates a population of around 11 000 people in 4300 dwellings. In addition to the housing, the development includes a school, a university campus, commercial centres, a golf club, and a large portion of wetlands and soft open spaces. The development has various integrated WSUD measures that focus on sustainable stormwater management and wastewater reclamation practices. The WSUD measures are similar to ones implemented in The Grove Precinct, the only difference being that the WSUD measures at Mawson Lakes cover a wider area.

The main WSUD measure in place is the dual reticulation system. The City of Salisbury (2011) describes this system. Two water sources, stormwater and treated wastewater, are used in the recycled water network. The two are mixed, disinfected, and the water is then sent to a storage tank where it is then distributed to the properties in Mawson Lakes. The treated wastewater is sourced from a nearby WWTP and the stormwater is collected from the wetlands within the development (City of Salisbury, 2011). Due to the variability in the volume of stormwater runoff, as well as the fluctuations in water demands, the surplus stormwater and treated wastewater is stored in local aquifers and extracted when necessary (Gardner, 2003). Figure A.2 illustrates the dual reticulation system, and the aquifer storage and recovery system. The pipes and fittings used in the recycled water system is different in colour to ones in the potable water system, this allows for easy identification of the two systems (City of Salisbury, 2011). The recycled water is used for toilet flushing and all outdoor uses except swimming pool filling. The savings on potable water were expected to be about 70% (Lloyd, 2001); a more recent report by Delfin Lend Lease (2007), the developers of Mawson Lakes, states this to be 50% (88 Mℓ/yr).

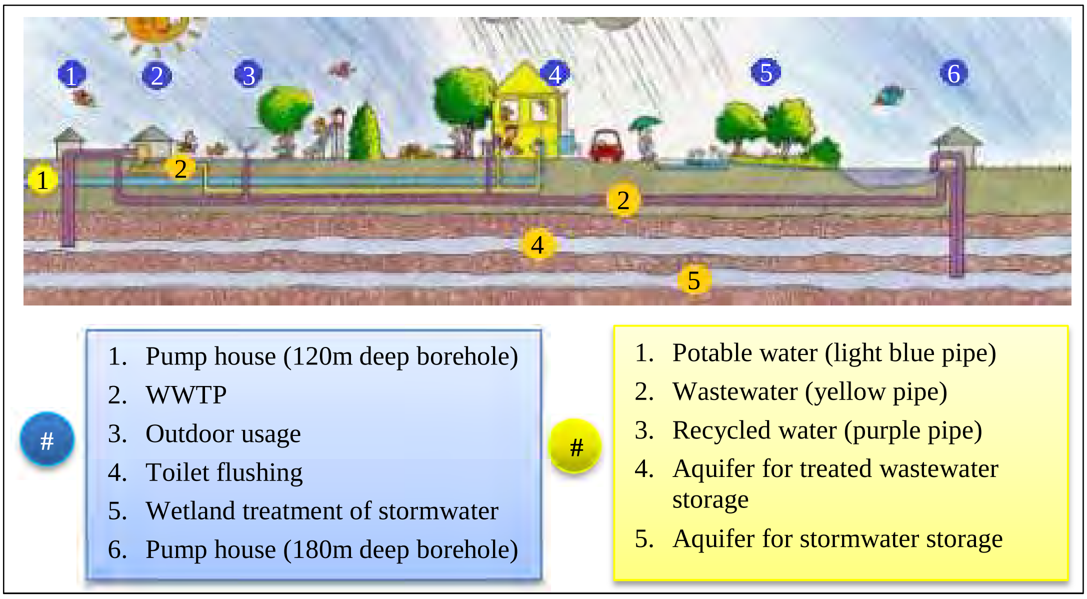


Figure A.2: Mawson Lakes, WSUD system (adapted from Lloyd, 2001)

The use of reclaimed wastewater poses a risk to public health and safety. The DTI (2007) explains that the success of the Mawson Lakes is partly due to the detailed monitoring and policing guidelines of the dual reticulation system. Special training is provided to personnel who maintain and operate the system; detailed contingency plans in the case of failure of the system were developed, and detailed plumbing guides were prepared in order to avoid cross-connections. Furthermore, water quality monitoring programmes and incident reporting protocols were put in place (DTI, 2007). These allow for problems to be addressed efficiently and systematically.

At the onset of the development, Mawson Lakes was an example of the vision of WSUD (Lloyd, 2001). The main focus of the development is the dual reticulation system, although various other WSUD measures, such as the aquifer storage and recovery and the use of stormwater as an alternative resource, were incorporated into the dual water reticulation system. In addition to this, the development has incorporated various other sustainability measures, such as the use of recycled materials, solid waste management guidelines, and solar power (Delfin Lend Lease, 2011a). As a result of all these measures and systems, Mawson Lakes has accumulated numerous environmental excellence awards (Delfin Lend Lease, 2011b), and it is an excellent example of an ecologically sensitive development.

A1.1.3 Further case studies

Table A.1 presents further integrated WSUD case studies. These case studies are similar to the two detailed cases studies discussed as they use a variety of technology and methods to manage all three components of the urban water cycle. Another case study, the Prince Henry Hospital Development, is presented in Figure A.3. This case study will not be described in detail, as the types of WSUD measures have already been discussed in other sections.

Figure A.3: Prince Henry WSUD strategy
(adapted from Landcom, 2009; background image from Google Earth)

Table A.1: Further integrated WSUD case studies in Australia

Case study and location	Doncaster Hill Green Civic Precinct, Melbourne (DEWHA, 2009)	CERES, Brunswick, Victoria (SEWaC, 2012)	Currumbin Ecovillage, Currumbin, Queensland (Tanner, 2007)
Scale and type	Local (community centre and library)	Local (community and educational facility)	Precinct, 144 households
Water conservation and local supply measures	Rain garden bioretention system and water saving devices	Rainwater harvesting, water saving devices, dry sanitation	Rainwater harvesting in 20kL and 40kL tanks
Wastewater treatment and re-use	Blackwater and greywater recycling; non-potable uses	Greywater re-use for toilets and irrigation; treatment with septic tank, and reed beds	Treatment via textile filters, microfiltration, UV; re-use for irrigation
Stormwater measures	Rain garden and bioretention systems	Green roof	Swales, bioretention filters and detention ponds
General comments	Various other energy saving measures	Projected water savings of 1 ML/yr	Models were used to design the Ecovillage (XP-SWMM, MUSIC, and MEDLI)

A1.2 Singapore – Movement towards a Water Sensitive City

Singapore's unique water context and political relationship with Malaysia have resulted in the development of water sensitive strategies to manage scarce water resources in Singapore. Singapore is a densely populated region with limited surface area, but high rainfall (Luan, 2010). Furthermore, according to the PUB (Singapore Public Utilities Board) there are no natural aquifers that can be utilised (PUB, 2012a). These natural restrictions have created a water stressed country that has resulted in Singapore developing alternative methods of water supply. According to Luan (2010), when Singapore gained independence from Malaysia in 1965, the Singapore government realised that its local reservoirs and imported water from Malaysia would not be sustainable for the growing economy and population. In response to this, the Singapore government explored alternative water sources and ultimately adopted a multi-faceted political, institutional and technical approach to water management (Luan, 2010).

In the last four decades, strategic planning and investments in research and technology have enabled Singapore to increase the robustness and diversity of their water supply through the development of an intricate IWRM plan – at the heart of which is the Four National Taps Strategy that aims to improve the sustainability of water resources by integrating and managing four identified water sources (PUB, 2012a):

i) Local catchment water.

ii) Imported water from Johar Bahru, Malaysia.

iii) NEWater.

iv) Desalinated water.

The first, third and fourth (local catchment water, NEWater, and desalinated water) are significant water sources. The PUB manages these sources in an integrated system. This system forms a closed loop and all three sources are used to their maximum capacity. This closed loop is illustrated in Figure A.4.

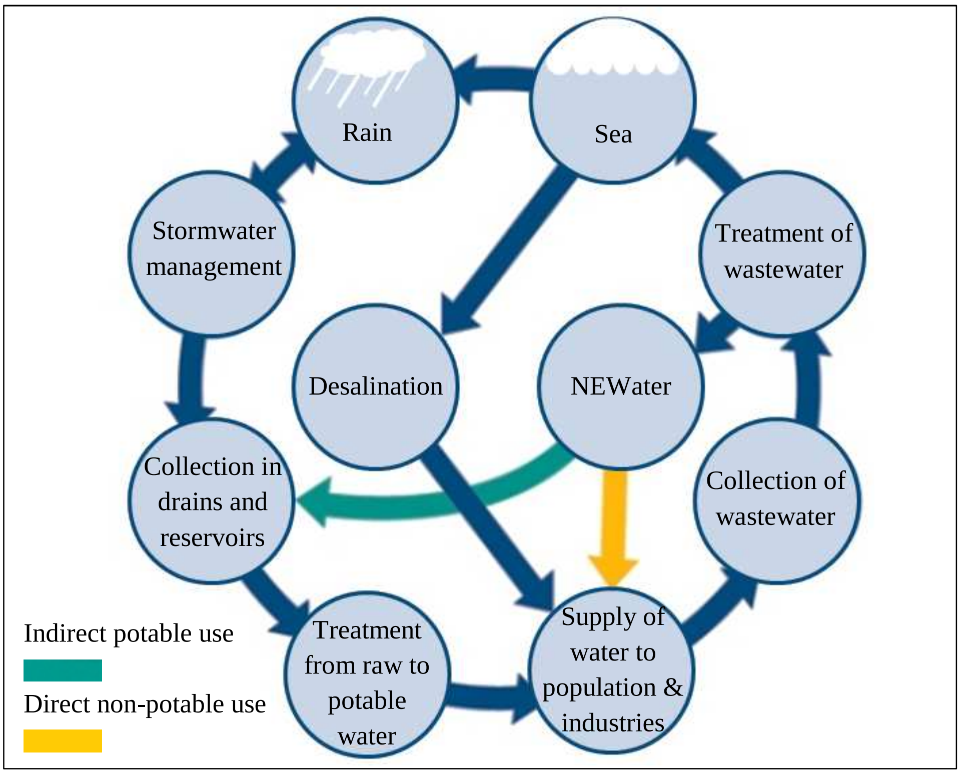


Figure A.4: Singapore's integrated urban water cycle (adapted from PUB, 2012a)

Local catchment water and NEWater are Singapore’s most significant water sources, and hence they will be discussed further. Local catchment water refers to surface stormwater that is collected. The Singapore government has constructed a network of drains, canals, and collection infrastructure to collect and transfer stormwater to one of its seventeen reservoirs. The scale is such that the urban catchment area as well as the catchment areas from the Marina, Punggol, and Serangoon reservoirs cover two thirds of the country (PUB, 2012a). There are plans to expand the catchment area to 90% of the country by 2060; however, this will depend on the success and rate of development of the Variable Salinity Plants (PUB, 2012a). A Variable Salinity Plant is a new type of water treatment plant that has the ability to treat water of a variable salinity. It can switch between treating seawater, freshwater, or a mix of the two, without changing the treatment infrastructure or stopping the treatment process; this allows for two water sources and a more cost-effective water treatment plant (PUB, 2012b).

NEWater is a direct non-potable wastewater re-use scheme and an indirect potable wastewater re-use scheme. The PUB (2012c) states that it took three decades of research and investigations to implement it. There are currently four NEWater treatment plants. The first two in Bedok and Kranji were commissioned in 2003. In 2007, the Ulu Pandan plant was commissioned, and in 2010, the largest plant was commissioned in Changi. Currently, NEWater supplies up to 30% of Singapore's water demand. Singapore plans to expand this scheme to 50% of the country's water demand by 2060 (PUB, 2012c). The PUB (2010) explains the NEWater scheme. Wastewater is collected via sewers and transferred to wastewater treatment plants where it is treated using membrane bioreactor technology. The treated wastewater is then sent to NEWater treatment plants where the treated wastewater is treated to potable standards using a multi-barrier treatment system, shown in Figure A.5. The effluent from the multi-barrier treatment process is called NEWater, and is sent for distribution and re-use (PUB, 2010). According to the PUB (2012c), the majority of the NEWater is re-used in industrial processes, as well as for air conditioning and cooling in commercial and institutional buildings. A small volume of NEWater is blended with raw water in the surface reservoirs where it is then treated and supplied to consumers as tap water.

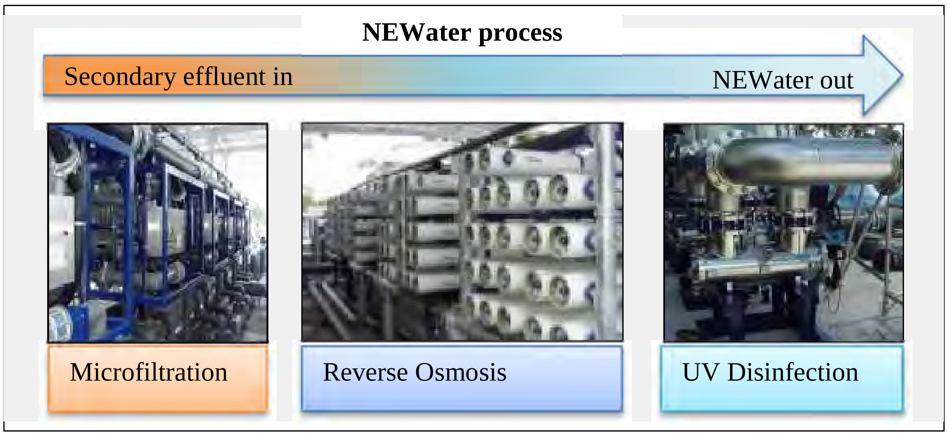


Figure A.5: NEWater treatment process (adapted from PUB, 2002)

The wastewater reclamation process forms part of the Deep Tunnel Water System (DTWS). The DTWS, as explained by the PUB (2010), *"is an efficient and cost-efficient solution to meet Singapore's long-term needs for used water collection, treatment, reclamation and disposal."* The system involves the collection and conveyance of wastewater in a conventional sewer network, and as well as two large, deep tunnels that cross the island. This network transports the wastewater to two centralised wastewater reclamation plants that have deep-sea outfall pipes for surplus treated wastewater. There are two phases in the DTWS, and currently Singapore has completed phase one. The DTWS is illustrated in Figure A.6.

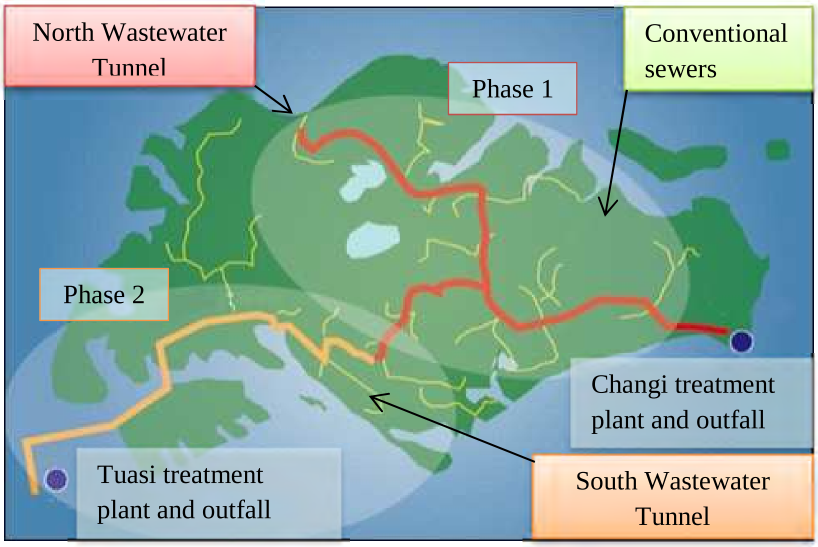


Figure A.6: Deep Tunnel Water System (adapted from Loganathan, 2008)

In addition to the integrated water management schemes discussed, Singapore has implemented numerous social, media, and educational campaigns to promote water sensitive activities. These programmes, as explained by PUB (2012a), aim to improve the value and appreciation of water bodies. The PUB encourages all stakeholders, who they refer to as the 3Ps (People, Public, and Private), to participate in water sensitive activities. The current campaigns include water conservation programmes (10% Challenge and 10-Litre Challenge), and recognition and awards programmes (Watermark Award and Friends of Water). Central to all these campaigns is the Active, Beautiful, Clean (ABC) Waters Programme.

The Active, Beautiful, Clean (ABC) Waters Programme aims to move Singapore to a Water Sensitive City by harnessing the full potential of water bodies. It involves the holistic integration of drains, canals, and reservoirs with the surrounding environment, primarily through the application of SuDS. As part of this programme, the PUB has released the *ABC Design Guidelines* (see PUB, 2011). This document provides reference material for various SuDS technologies and strategies. The aim of this document is to promote SuDS and the ABC Programme to property developers, architects and engineers. Some innovative SuDS are presented in this document, and these are shown in Figures A.7 to A.9. The PUB (2012a) plans to implement over a hundred SuDS projects in the next 10-15 years.

Figure A.7: Sequential vegetated cleaning system – actual (left), conceptual (right)
(adapted from PUB, 2011)

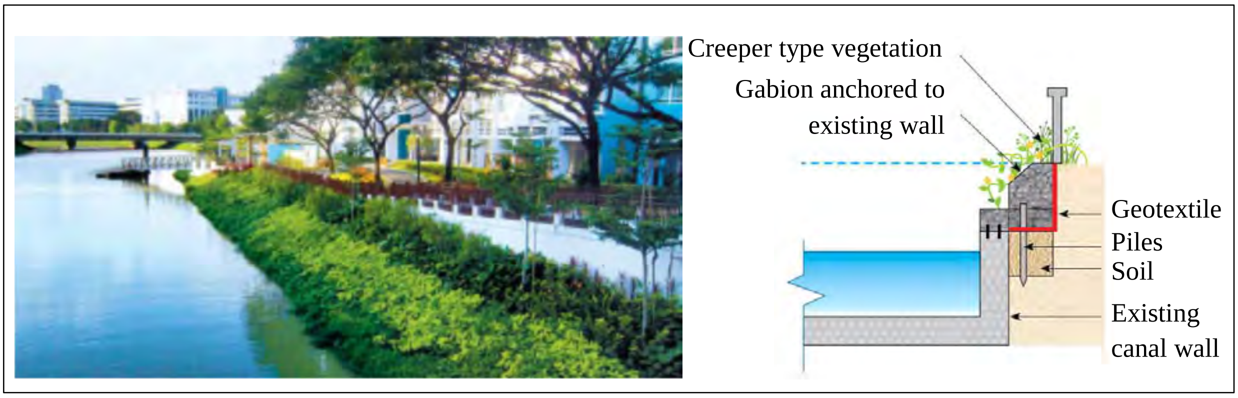


Figure A.8: Vegetated canal waterways – actual (left), conceptual (right) (*ibid*)

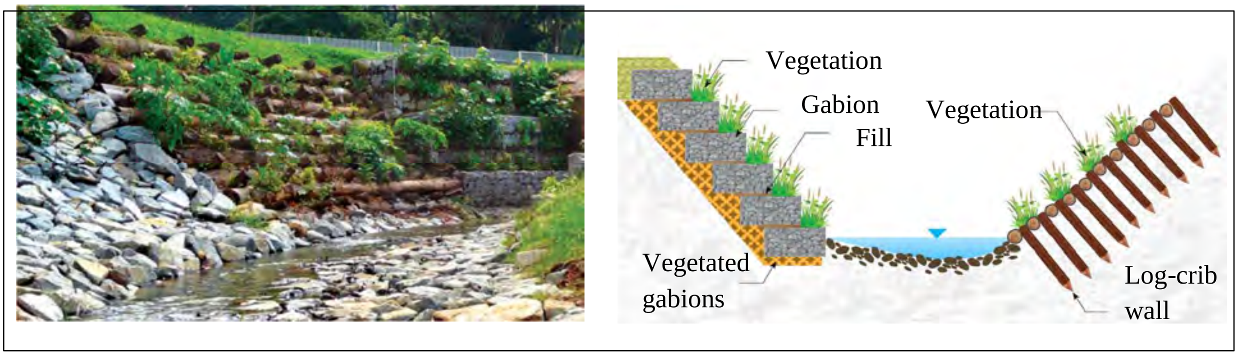


Figure A.9: Bioengineered slope stabilisation – actual (left), conceptual (right) (*ibid*)

The ongoing success of Singapore is an excellent case study to show the benefits and importance of water. As a result of all of Singapore's efforts, Singapore is at the forefront of the Water Sensitive City movement. It frequently shares its experiences with the international community and has provided a platform for institutions, leaders, and experts involved with the water sector to share knowledge and address global water issues.

Appendix B

Institutional Review

B1 Introduction

This report examines the institutional arrangements in South African metropolitan local governments in response to 'Water Sensitive Urban Design', or WSUD. The following question was addressed: to what extent does the structure and functioning of urban water management give effect to the principles of WSUD? Related to this, how is the management of urban water resources structured in municipalities, and what is the level and nature of cross-functional co-ordination and integration of activities between specialized departments responsible for specific components of water resource management?

The term 'Water Sensitive Urban Design' represents a policy amalgam which according to its proponents 'reflects a new paradigm in the planning and design of urban environments that is sensitive to the issues of water sustainability and environmental protection'. Moreover, according to the WSUD research proposal terms of reference (WRC proposal no. 1002315), the concept reflects an emphasis on 'integrating the holistic management of the urban water cycle [Water Sensitive] into the planning and design of the built [urban] form …' The term is essentially composed of two parts: 'Water Sensitive' and 'Urban Design'. The bi-partite character of the term denotes an expansion in its original conception from using stormwater drainage as a water resource (i.e. through concepts such as Sustainable Drainage Systems, SuDS), to assessing whether other municipal functions, such as urban design and planning, wetlands conservation, water demand management and wastewater re-use could augment the security of water supply in the face of increasing and multiple demands through enhanced co-ordination and integration. The core features of WSUD include: protection of natural landforms on which water is stored and travels; protecting the quality of surface and groundwater, including through wastewater treatment processes; attenuating stormwater runoff to manage the impact on receiving eco-systems and recognizing the value of stormwater for recreation and landscaping; and reducing the demand pressure on available water supplies including through re-use (QDIP 2009, in Armitage *et al*., 2012).

A critical issue facing South African urban local governments is balancing security of water supply with the acute demand pressures created by decades of disproportionate and unequal access to this crucial resource. Whilst increasing global population levels coupled with high density urban settlements have placed significant strains on the supply and distribution of critical resources such as water, the necessity of conservation, efficient resource use, management and protection are especially acute in countries such as South Africa which exhibit high levels of poverty, inequality and historical service scarcity.

WSUD is driven by an imperative to plan and engineer urban landscapes to prioritise conservation, efficient resource use, and balancing security of supply and management of demand. These matters typically adopt and become entwined in specialised scientific concerns relating to such issues as catchment hydrogeology, the architecture of urban planning and design, green engineering, as well as conservation and climate change mitigation. These measures are further entwined in an amalgam of functionally-specialised knowledge spanning civil engineering, hydrogeology, urban planning, and conservation and natural resource management. The objective for this section of the study was therefore to try to translate the need for these physical imperatives of urban planning for sustainable water resource management into an assessment of the institutional arrangements that either facilitate or impede co-ordination and integration.

These enablers and obstacles / challenges have been assessed by examining the institutional arrangements that metro local governments in South Africa have put in place to render urban planning, the various technical services involved in the delivery, storm and wastewater management, as well as environmental management services. This report is primarily concerned with the extent to which metro local governments exhibit signs of coordinating or integrating their specialised disciplinary knowledge and functional activities in response to WSUD principles.

B2 Research methodology

This institutional review was based on four (4) case studies of metropolitan local governments in South Africa: Cape Town, eThekwini, Johannesburg, Tshwane. The selection of these four metropolitan areas was primarily informed by the acute conservation and demand challenges facing these high density residential and industrial settlements. The analysis was largely qualitative in nature, combining a review of primary and secondary documents which, in the former case, included primary documents published by the four cities. 16 non-random, face-to-face[1], key informant interviews were also carried out with officials from each city representing various line functions involved in urban water management[2]. In most cases these interviews involved more than one official being present which resulted in 26 officials participating in the interviews. The bulk of the interviews were carried out during September and October 2012; with the remaining interviews conducted in July and September 2013. An interview schedule was devised (section B11) to acquaint all participants with the nature of the enquiries as well as to focus and guide the analysis. In practice it was found that the interview schedule was more useful as a flexible guide or list of talking points to stimulate thinking about WSUD and subsequent discussion, rather than a set of questions to be rigidly adhered to by the participants.

Limitations in the research were primarily due to the inability to include more key informants in the interview phase; given the nature of the study which required the inputs of a variety of officials whose functions impact on the urban water cycle. This was compensated through sourcing mainly primary sources published by the metros. Finally, the intention of this review was to conduct an exploratory examination of institutional responses to the principles of WSUD at the municipal level of government, focusing on metros. To this end, this study did not attempt to evaluate or assess local governments, individually and comparatively, on their implementation of WSUD, given that it does not constitute a distinct and uniform policy prescript as much as a set of objectives for managing urban water resources across various line functions. The report is therefore an attempt to analyse the organisational, policy and regulatory conditions under which water resource management is currently being pursued, in the hopes of generating a clearer picture of how municipal responses to WSUD could be enhanced in the future.

[1] Due to scheduling difficulties, two of the interviews were conducted over the telephone.
[2] Four interviews were carried out in Cape Town; four in eThekwini; four in Tshwane and four in Johannesburg.

B3 Background

The background to the institutional review outlines the assumptions that were employed to guide the enquiries into the institutional arrangements that exist in metropolitan local government in response to WSUD principles. The primary focus was an examination of the **organisational structures** and associated activities of the line functions which are collectively responsible for managing urban water resources, where WSUD requires enhanced coordination and integration of various specialised municipal functions and services. However, background research in the form of a draft literature review (Armitage *et al*., 2012) made several observations about the institutional barriers inherent in the organisational design of South African metro local governments, which would hinder the adoption of a holistic or integrated approach to managing urban water resources. These observations were treated as assumptions in empirically examining the specific institutional arrangements in the four metros under study.

The literature review observed that the line functional arrangements for urban water management 'compartmentalises' the core water functions of supply, storm and wastewater services; which are further split from other relevant functions in the WSUD scenario, especially environmental management (section B9). This arrangement is said to have evolved according to a technicist approach to engineering solutions for managing urban water resources at the expense of promoting the environmental or ecological value of the resource. Moreover, a key concern has been that this arrangement has hampered inter-departmental communication for promoting integrated water management. The literature review further proposes that a 'significant restructuring' will need to be made to urban water institutions. Finally, the implications of a WSUD-oriented institutional arrangement would elevate an ecological approach above that of a technicist approach, which would include institutional arrangements that 'consider entire catchments'.

These observations were again treated as assumptions in proceeding to examine the actual institutional arrangements for urban water resource management. As such they raised and left unanswered several questions about the ideal organisational scenario which would need to exist to effectively promote a WSUD approach. Firstly, how functionally-estranged are the various services regarded as critical to urban water management, especially environmental management from engineering-based planning and implementation of water management? Put another way, are 'environmental considerations' completely absent from conventional engineering-based water services, or incorporated as an add-on? Related to this, has this arrangement made it 'very difficult' in practice for distinct line functions to communicate? Secondly, have existing line functional arrangements not already incorporated some aspect of an ecological approach to configuring urban water management services, in response to the argument that 'water management strategies should consider entire catchments to ensure that planning incorporates all aspects of a watercourse' (Niemczynowicz 1999, in Armitage *et al.*, 2012). Thirdly, the literature review advocates for structural re-organisation but was not able to clearly indicate what form this should take. The assumption is that the logical form that restructuring would take would be to integrate distinct line functions into some 'multidisciplinary' form. The clearest the literature review gets to illustrating this includes joining stormwater management with water and sanitation, which is responsible for supply and wastewater services. The question remains however whether the integration of these services to promote WSUD would otherwise engender functional compatibility. Finally, the literature review refers to both structural 'integration' as well as 'co-ordination', which need to be distinguished as the former is more prevalent in the discussion. Having said this, co-ordination does not necessarily result in or necessitate structural re-arrangement, where the literature review observes that the 'challenge facing the successful implementation of sustainable urban water management will be the establishment of cross-sectoral coordination between different role players' ((Niemczynowicz 1999, in Armitage *et al*., 2012).

The aforementioned interpretation of the literature review concerning institutional barriers to promoting WSUD therefore prompted a more detailed probe into the implications of these barriers. The task of this institutional review was to identify what functional disincentives impede efforts to work more closely across functional lines, or alternatively, to determine what factors prompt instances in which there has been enhanced co-ordination, such as in the form of demonstration or pilot projects (WRC, 2010). This has resulted in posing questions such as: how are organisational divisions responsible for the planning and management of the urban water cycle currently structured and operating?

Questions such as these are salient due to the draft literature review's argument that the challenge facing WSUD stems from a lack of institutional commitment to employing methods and technologies that promote this cross-disciplinary concept. Apart from methodological estrangement amongst municipal officials (e.g. engineers, planners, environmental scientists), and the jurisdictional separation within core water service functions, the literature on policy co-ordination has also noted that horizontally co-ordinating the work of functionally-specialised entities can overburden their ability to focus on core activities, by stretching available human and financial capacity (Bakvis & Juillet, 2004; in Christensen & Laegreid, 2007). Moreover, the formats in which functional activities are carried out, including distinct budgeting and accounting procedures can also impede integration and scupper efforts to derive financial savings from cross-cutting work (WRC, 2010).

Although the primary focus was on analysing intra-organisational line function arrangements within the four metros, the presence of an enabling policy environment for WSUD is often crucial for the ability of organisational structures and officials to co-ordinate their efforts. In this regard, what is the policy receptiveness of urban local governments to WSUD, including as outlined in strategic and sector-specific planning and guideline instruments; as well as in distinct programmes or projects straddling various line functions which contribute to the management of the urban water cycle? The analysis was therefore attuned to potentially conflicting policy priorities which can have a direct effect on designing urban spaces in a manner that is sensitive, i.e. protective of surrounding water resources. For example, densification pressures and demand for housing and potable water can crowd out efforts to design low impact water sensitive infrastructure.[3]

Related to analysing the policy environment was examining to what extent the legislative framework governing urban water management can facilitate the application of WSUD principles. This could entail probing the importance of by-laws. Alternatively, should urban local governments try to 'force integration' by ensuring that building regulations, planning regulations and water and sanitation standards contain the rules necessary to require cross-functional integration? (WRC, 2010)

[3] The inaugural reference group for the WSUD project (WRC, 2012a) saw a participant comment that urban sprawl led to longer distribution mains which raised the potential for more leaks. The participant also argued that the funding policies driving housing development resisted alternative methods for the provision of housing.

B4 Organisational arrangements for urban water management

This section outlines the formal organisational arrangements in the four metropolitan municipalities. It will specifically assess to what extent these arrangements conform to the assumptions made in the literature review, which also mark impediments to promoting WSUD principles. The information presented herein was extracted from primary documentation such as organisational diagrams, and supplemented by interviews.

The first assumption concerns the ‘compartmentalisation’ of core (e.g. supply, storm and wastewater) and ancillary (e.g. environmental management) urban water management functions. The functional arrangements in the metros generally conform with this arrangement, where stormwater management is paired with roads and transport, which operates separately from the supply and treatment of water, which is typically housed in a department of water and sanitation. Having said this, notable differences are evident. To begin with, the cities of Cape Town and Tshwane reflect the basic separation of stormwater from supply and wastewater management at the major sub-division: where the reticulation and treatment of water is housed in Utility services (Cape Town) and in the Public Works and Infrastructure division (Tshwane), which function separately from the Transport, Roads and Stormwater division (Cape Town) and Transport and Roads division – which contains a Roads and Stormwater section (Tshwane).

The situation is however different in Johannesburg and in eThekwini. In the former case, the major sub-divisions below the level of City Manager also split stormwater management from supply and wastewater treatment, although these services are further split organisationally with the creation of ‘municipal-owned entities’ or ‘state-owned companies’ (SOC), responsible for direct delivery of a service, which function under the oversight of traditional departments. In this instance, an ‘Environment and Infrastructure Services’ department, which is the major sub-division, oversees wastewater services and reticulation, which in the latter case is carried out by Johannesburg Water, a SOC; and where a Department of Transportation, which sets and regulates stormwater policy, oversees the Johannesburg Roads Agency, also a SOC, which is responsible for stormwater management. eThekwini deviates from its metro counterparts, where the major sub-division of ‘Procurement and Infrastructure’ (excludes ‘Housing’), under the direction of a single Deputy City Manager, contains both departments for Water and Sanitation, as well as ‘Engineering’, where the latter consists of Roads and Stormwater Maintenance, and Coastal, Stormwater and Catchment Management. In this instance, although water and sanitation and stormwater remain organisationally separated, this is at a lower sub-division compared with the other three cities.

The second assumption relating to the compartmentalisation of urban water management functions is that this has side-lined the adoption of an ecological or environmental focus to engineering these services. At a general level, this also appears to be borne out in practice, although there are notable exceptions in relation to how an ‘environmental’ role is defined. At a formal level, metro responsibilities for environmental management are typically housed in a separate major sub-division, such as in Cape Town: ‘Economic, Environmental and Spatial Planning’; Tshwane: ‘Agriculture and Environmental Management’; and in eThekwini: ‘Sustainable Development and City Enterprises’. The situation has however recently changed in Johannesburg, where the major sub-division now combines Environment with Infrastructure and Services, under which water and sanitation sits. Moreover, the directorate responsible for Water Quality and Catchment Management (WQCM) also resides within this major sub-division, and so sits astride the water delivery function (Interview 16).

This restructuring seems though to have only partially addressed the major concern that urban water management, especially of core water service functions, remains separated, given that stormwater remains under the jurisdiction of a separate Transportation department. Having said this, it was evident that there is within Environmental Management strong advocacy for ingraining WSUD principles in stormwater management in particular (Interview 12). Although the recent timing of this change in the city does not alter the fact that at a strategic level environmental management continues to function separately from the main water resource management functions in the metros overall, WSUD advocates would be advised to monitor the operational effects which transpire in the wake of this structural change in Johannesburg.

A further look at the level of attention given to ecological / environmental concerns in the core water services functions also invites a more detailed analysis of the extent to which activities that have an ‘environmental’ focus appear to be have been tacked onto core water services functions, as observed in the literature review. For example, an ‘environmental’ focus has in fact been incorporated into the stormwater management function, as opposed to sitting astride from it, in at least three of the metros (excluding Johannesburg). This challenges the assumption that there is a separation of ‘environmental considerations from the engineering’ elements in pursuing a sustainable water management strategy (Armitage *et al.*, 2012). For example, Cape Town has a ‘Catchment, Stormwater and River Management section within its Roads and Stormwater branch, which although primarily staffed by civil engineers also includes an environmental scientist specialising in water ecology, or otherwise requires engineering staff to execute hydrological functions which have a trans-disciplinary scope (Interview 3). A similar arrangement is in place in eThekwini, where the Coastal, Stormwater and Catchment Management section sits within the Engineering branch of the Procurement and Infrastructure division. The Catchment management section also supplements its engineering staff with other skill sets which include an environmental advisory officer, as well as education and advocacy officers who work at a catchment level to promote awareness amongst community members in maintaining catchment health (Interview 5). In Tshwane, although less visible in its formal designation, the Integrated Stormwater Planning section within the Roads and Stormwater branch also carries out an environmental management function at a catchment level, together with the city’s Environmental Management department. This includes ‘joint’ management arrangements with the former on river maintenance, focusing on issues such as sedimentation, siltation, and flooding (Interview 9). These observations also suggest that administrative arrangements have, in some measure, already accommodated planning and implementation at a 'catchment' level to address ecological concerns.

Although Johannesburg is an exception in not formally adjoining the environmental management function with stormwater management, it has devised co-ordinating structures to link the two functions. This includes a 'Water Quality Task Team[4]' to look at the impact of water services departments on the city's water quality, which is the remit of the Water Quality and Catchment Management directorate. The convening of the task team, which dates to 2010, was prompted by queries directed to the WQCM directorate by political office bearers about how threats to water quality were being dealt with. As WQCM sees itself as the 'recipient' of water quality problems produced as a result of the operations of other agencies – e.g. pollution due to poor sewer infrastructure, and the effects of stormwater runoff on erosion and siltation – the Task Team is viewed as a forum that can facilitate joint responses to water quality problems and to allow WQCM to try to 'influence' the business plans of water services agencies to take environmental mitigation[5] into account (Interview 16).

In addition to some movement towards trans-disciplinarity of both staff and functional roles, it was also conveyed in interviews with municipal officials in at least three metros that increasing emphasis is being placed on augmenting the knowledge and skills of engineering staff to promote a more holistic (e.g. natural environment-oriented) approach to stormwater engineering in particular, informed by SuDS. For example, the metros which housed 'catchment management' sections within their stormwater branches spoke of: the need for engineering staff involved in catchment planning to learn different skills (Cape Town); engineering staff experimenting with and adapting to SuDS approaches, despite the need for more explicit South Africa-specific guidelines and building this into professional accreditation (Tshwane); and attempts to augment the specialist technical knowledge of engineers by exposing them to other aspects of the water management cycle which, because of staff shortages, constrains efforts to 'create the [spare] time to create cross-sector knowledge' and 'build in redundancy' for re-training efforts (eThekwini) (Interview 5).

Finally, the compartmentalisation of urban water management does not in reality conform to a complete separation within core water services functions, especially across related functions such as environmental management. Given this, and the fact that the literature review speaks about both integration and 'co-ordination', where the latter does not necessarily warrant re-organisation, contemplating structural integration as a WSUD catalyst should not be treated as a *sine qua non* as opposed to a discretionary option subject to co-ordination effectiveness. Moreover, structural integration at a line function level did not arise in the interviews with metro officials, except for one suggestion to combine stormwater management with environmental management to form a kind of 'water care management department' (Interview

[4] The membership of the WQTT comprises the WQCM directorate, JRA, Johannesburg Water, Pikitup; and the issues which it deals with straddle operational and capital matters covering problems resulting from pollution, river bank erosion, and waste management.

[5] For instance, the existence of 'emergency stormwater projects', including floodline studies to determine the risks to development, were noted to be taking place in the JRA (Interview 14).

9). This is unremarkable though given that functional specialisation is ingrained in public sector institutions which can also inculcate a kind of 'logic of appropriateness' (March & Olsen 2006) amongst officials who carefully filter and mediate the situations under which they believe they can and should work across functions. Officials were more inclined to suggest that structural reform to drive WSUD should happen at a non-line function executive level ('higher up' the organisational chart) in which it is driven from the level of a metro's executive or 'corporate' management, which could facilitate inter-departmental co-ordination and ensure that additional resources are earmarked (Interview 9; Interview 3). A concrete example of this is the creation of 'clusters' at a major sub-division in Johannesburg, where the 'Sustainable Services' cluster includes departments and agencies responsible for environmental management and the key water services functions: JRA, Johannesburg Water (Interview 16).

B5 Institutional responses to Water Sensitive Urban Design in metropolitan local governments

This section outlines the conditions under which WSUD is being responded to by the metros under study, and highlights areas where this response can be strengthened. In attempting to frame the presentation of the findings, it is necessary to revert to a practical definition of WSUD, which according to Australia's Queensland Department of Infrastructure and Planning referred to in Armitage *et al*. (2012), is a multi-faceted idea that straddles multiple functions within a municipality. This includes the protection of natural water reservoirs, courses and eco-systems; attenuating stormwater runoff; promoting re-use of both storm and wastewater; and reducing the demand on potable water through more efficient use of existing supplies. Despite its multi-dimensional character, the various elements which make up WSUD are held together by an overarching emphasis on co-ordinating and integrating the work of water-related service functions within a municipality, based on the logic that the management of water in its various usages is inherently inter-connected. Whilst there may be evidence of municipalities responding to individual WSUD principles, this does not necessarily translate into corresponding levels of co-ordination and integration across water-related services, which is a higher-order expectation, and which should be treated as distinct from individual service responses.

B5.1 Individual service-level responses to WSUD

At the level of individual service provision, the four metros did exhibit evidence of a response to WSUD principles. In Cape Town the approach to managing water, which in the past focused on security of supply to meet demand growth, seems to have shifted to demand-driven management. The city states that Water Demand Management and Water Conservation (WC/WDM) initiatives are the best ways to meet increasing demand for water-related services as opposed to increasing supply to meet that demand (CoCT, 2011c: 132). Moreover, the emphasis on demand management has also recognised the importance of internal co-ordination within the city's administration, with the former Cape Metropolitan Council adopting, in 1999, an Integrated Water Resource Planning strategy (CoCT, 2007b: 9). The city is intending to formalise a 20 year plan for co-ordinated development during a 5 year Integrated Development Plan 2012-2017, in response to what has been termed uncoordinated growth, development, inappropriate spatial and town planning, and a lack of coordination between departments (CoCT, 2009d: 35).

Elsewhere, an 'integrated' approach was cited amongst water services departments in Cape Town. For example, the city's Water and Sanitation department (W&S) has developed an Integrated Master Plan with the aim of ensuring long term sustainability in service provision.

The scope of integration however appears to be largely confined[6] to the functions within W&S, which include services such as bulk water management, water treatment plants, and reticulation. The Plan's objectives include balancing demand and supply where all water and sanitation regional offices will make use of the same information and data, ensure all infrastructure plans within W&S are aligned, and provide reliable information for budgeting and to keep the plan updated on an annual basis (CoCT, 2011c: 31). This type of planning would include infrastructure, services and budgeting (CoCT, 2007b: 19).

eThekwini is engaged in various initiatives that correspond with individual WSUD principles. This includes a programme to improve poor river water quality through activities which minimise overflow from the sewer reticulation system into rivers, otherwise known as the Green Rivers Programme. These activities include infiltration and accumulation of silt, illegal stormwater ingress, fats, and illegal discharges of toxic pollutants (eThekwini Municipality, 2011: 47). Sewers are being cleaned in order to remove large deposits of silt and foreign objects and the first area of focus in this regard is the sewer reticulation system in the catchment of the Umgeni River. Levels of silt accumulation are also being measured in order to establish plans for future cleaning of sewers. New systems for the monitoring of pump station overflows and failures are being installed and the identification of pumps and equipment for replacement is being carried out. Monitoring is also being undertaken through the extension of an aquatic bio-monitoring programme and the possibility of remote as well as automatic sampling of industrial effluent is being explored (eThekwini Municipality, 2011: 47, 53). The city's Environmental Planning department also appears to be indirectly involved in the effluent monitoring process, having expressed some reservations about the technical criteria associated with the level of national government's Green Drop accreditation (Interview 8). This appears to correspond with the department's more direct role in monitoring the impact of development on the environmental assets of the city, i.e. by way of 'eco-system servicing', which assesses the value of 'free' services provided by the environment, e.g. wetlands and floodplains.

The eThekwini Water and Sanitation department is undertaking a feasibility study into reusing treated effluent for potable use. The proposal that is being taken forward by the city will see treated effluent from two wastewater treatment works being reclaimed and treated to potable levels. An Environmental Impact Assessment is planned in order to assess this proposal, subject to the completion of a rapid reserve determination by the Department of Water Affairs (eThekwini Municipality, 2011: 70). Elsewhere, examples of wastewater re-use go back to 1999, where a public private partnership was established – Durban Water Recycling (a wastewater recycling plant situated in the south of Durban at the Southern Wastewater Treatment Works) – to produce non-potable water at their water treatment plants which was then sold to a paper mill and a refinery for industrial uses (South Africa Cities Network, 2011: 114; eThekwini Municipality, 2011: 26).

[6] Though due to the growing density of informal settlements combined with the desire to eliminate sanitation backlogs, the W&S department has sought to integrate its service provision programme with the city's 10 year Housing Plan, drafted by its Housing department (CoCT, 2011c: 9).

Johannesburg's response to WSUD is evident in a number of initiatives. One of the city's flagship programmes is Urban Water Management. The focus of the programme is on repairing existing infrastructure to reduce the amount of water lost, the implementation of water demand reduction measures, the investigation of alternative water sources and the implementation of Sustainable Urban Drainage Systems (SuDS) as well as urban water harvesting[7] (CoJ, 2012a: 69; see also CoJ, 2012b). In addition there is also a focus on reducing water demand, treatment of wastewater and the re-use of Acid Mine Drainage as well as the development of sustainable urban drainage designs (CoJ, 2011: 76-77). The focus of the city's environmental policy also encompasses WSUD-relevant goals such as responding to the effects of climate change; the sustainable management of waste streams, the protection of its river ecosystems, water conservation, biodiversity conversation and environmental heritage management as well as building awareness and capacity for environmental management (CoJ, 2011: 21).

Tshwane covers an extensive area with varied development needs, urban and rural areas as well as significant open spaces and environmentally sensitive areas. Urbanisation has also not taken place at the same extent across all areas. The city has an outward urban expansion which causes continuous pressure on the capacity of the municipality to provide services and infrastructure to these new developments and on the ability of the City to maintain and monitor existing services and infrastructure (CoT, 2012a: vi). The city lacks an adequate maintenance budget, where the current allowance does not meet challenges which include the need to expand service networks due to growth and development and aging infrastructure. Moreover, the roads and stormwater infrastructure is not as directly affected by the infrastructure challenges facing water and sanitation services (W&S) (CoT, 2009, 13). This is exacerbated by insufficient human resources in W&S, with approximately 1700 positions in the W&S division in 2009 being less than 50% filled, and where vacancies straddled management, technical, operations and support functions (Fair, Loubser & Sherrif, 2009: 3).

As with the other metros, demand management is a key priority for Tshwane's W&S department. The city has approved a programme to boost its ability to supply water, developed in light of the Vaal River system being severely stressed and unable to keep up with the demand placed upon it. It is the city's aim to reduce the demand placed on the Vaal River System by developing its own water resources (CoT, 2012a: x). This Water Augmentation Programme depends on the re-use of treated effluent from the wastewater treatment works (*ibid*). However, these augmentation programmes are very costly and so water conservation and demand management remain a high priority. The reduction and monitoring of water losses is therefore a primary focus for W&S (Fair, Loubser & Sherrif, 2009: 2). As with other metros, W&S is also directly involved in pollution control of discharges into streams (Interview 10). Despite these efforts, the acute resourcing and infrastructure constraints faced by W&S does have implications for its involvement in broader and more co-ordinated efforts to promote WSUD.

[7] It was reported in an interview that Johannesburg Water had viewed the city as 'sub-catchments', where this appeared to refer to the potential for rain water harvesting (Interview 14).

B5.2 Co-ordinated service-level responses to WSUD

Moving from an individual-level service response to a co-ordinated level response to WSUD indicates that municipalities are exhibiting varied levels of co-ordination. It may be said that this spans a spectrum ranging from limited interaction which could be viewed as a by-product of core line function activities, or restricted by the conditions under which these activities are carried out – where these intersect with another line function, or where there is as yet unrealised potential, to more intensive attempts to co-ordinate functions to manage cross-sectoral water resource issues. The latter side of the spectrum can be considered more desirable in terms of promoting WSUD.

B5.2.1 Co-ordinated service-level responses to WSUD (limited interaction)

On the more limited side of the spectrum, the extent of functional interaction in Cape Town between W&S and other departments involved in water resource management appears to be motivated by troubleshooting problems that interfere with the provision of W&S services. For example, W&S has identified ingress of stormwater into sewers as a problem (CoCT, 2011c: 167). As a result, stormwater is presented in W&S policy documents as a problem in carrying out the water and sanitation function, though the commercially-sensitive nature of the W&S service, which has since 2001 operated as an internal business unit, may account for this view given the cost implications (CoCT, 2011c: 36). It was elsewhere acknowledged that W&S does interact with the stormwater management section in promoting demand management through waste and stormwater re-use (Interview 3). There have also been attempts to try to spatially align the planning of new wastewater treatment plants and the re-use of treated effluent with existing industrial and agricultural activities (Interview 4). For example, golf courses and some parks and sports fields make use of effluent from the City's 22 waste treatment plants, as do a few industries (CoCT, 2011c: 142). Elsewhere, a key activity for W&S in which it interacts with stormwater management involves the monthly monitoring and reporting on the quality of treated effluent being discharged into river systems, as well as sewage spills (Interview 4).

Remaining with Cape Town, it was recognised that urban design, which sits in the spatial planning portfolio, should ideally be treated as a key 'support' or 'advisory' service to line function technical services including those responsible for water management. A key constraint facing this ideal scenario has however been a lack of staff, where the city's urban design capacity is presently overstretched and constrained by other functional priorities, such as reviewing planning applications (Interview 1). The city's urban designers do interact directly with water services departments such as stormwater management, which as a result of available staff resources and the nature of the development, e.g. privately financed developments (Interview 3), typically occurs on a 'case by case' basis. It was also evident however that mainstreaming a role for urban design in water services planning also faces a perception problem. In order for urban design to avoid the label of being either a 'threat' to or an undervalued 'nice to have' addition to the planning undertaken by line function departments, it should not be viewed as professionally distinct from, but rather 'integral' to, the line function planning process (Interview 1).

Moving to Tshwane, it was mentioned that the resourcing and infrastructure constraints faced by the W&S department had implications for its involvement in broader and more co-ordinated efforts to promote WSUD. In reality the implications appear to be mixed, with clear recognition of the importance of re-use and water quality, but where W&S operates under relatively high cost-sensitive conditions where costs are ring-fenced and need to be strictly managed (e.g. water loss/leak detection, unaccounted for use) to ensure that income generation can support current and future supply and infrastructure needs such as wastewater treatment upgrading. In practice, this has resulted in W&S arguing that it needs greater regulatory flexibility from the city's central administration to manage its costs (Interview 10). This also implies that under these conditions W&S may be resistant to central efforts to increase co-ordination of its services with other water resource management functions.

Recent efforts by Tshwane's Planning department to develop a framework for what might be described as policy clustering, or grouping the municipality's various line function departments according to policy outcome areas, points to an as yet unrealised potential for promoting cross-sectoral initiatives, such as WSUD. Through a Capital Investment Framework, the metro's City Planning department is seeking to prioritise line function infrastructure spending according to outcome areas related to the following groupings: Basic Services and Socio Environmental Infrastructure, Strategic Investment Development and Attraction, and Spatial Restructuring. The Framework, which is in the early stages of roll-out, is intended to guide and prioritise infrastructure spending at a departmental level, by urging line functions to co-ordinate these investments at a spatial level, prioritising nodes or corridors within the city. It was the view of the City Planning department that the concept of WSUD could fit into the Basic Services and Socio Environmental infrastructure outcome area[8], although it is at a localised level where the concrete influence of the CIF on promoting WSUD principles will have to be observed. For now, City Planning referred to the Hatfield re-development area where some WSUD principles are being put into practice, although it also acknowledged that, from its perspective, there was not a lot known about WSUD (Interview 11).

In eThekwini, apart from clear efforts to promote wastewater treatment and re-use, the W&S department conveyed general concerns about the level of co-ordination between urban planning and services functions such as W&S, including the tendency to not design around available service infrastructure, which placed the latter in a 'reactive' position. Concerns were also expressed about the level of consideration given, at the development planning stage, to the technological requirements for effectively treating some types of industrial effluent before discharge, and which were not being treated at source (Interview 6). Notwithstanding concerns about the level of co-ordination between urban planning and services functions such as W&S,

[8] According to documentation on the CIF, this outcome area includes the Water and Sanitation and Roads and Stormwater departments (CoT 2012b).

there was a recognition from both departments that this was ‘better than it was’ (Interview 6). Moreover, concrete examples of synergy between urban planning and W&S were evident, including in the Cato Ridge area, which took into account the impact of a development on a neighbouring catchment area: industry was restricted to ‘dry industry’ to prevent contamination of a nearby dam. Another example was in the city’s northern corridor (Dube Port), which mostly hosts logistics industries and where all industry was restricted to dry, where the planning can accommodate industrial and domestic waste / sewage recycling (Interview 7).

A broader concern expressed by the city’s Development Planning section, which speaks directly to the efficacy of cross-departmental co-ordination, was the inability of the city to finalise a set of guidelines to define and prioritise sustainability to mitigate the environmental effects of growth and the demand for space (Interview 7). The department made specific reference to the city’s as yet incomplete ‘strategic environmental assessment’ (SEA), as a tool which could facilitate inter-departmental planning synergy. The department noted that their existing plans acknowledged the scarcity of water and river health, but added that the finalisation and application of an SEA, a process which had become stalled in the city due to funding limitations, variable commitment and priorities attached to it across line functions, could test its remediation proposals. The city had already spent considerable time developing a methodology for the SEA, with the department currently seeking funding from the provincial government to move ahead with a scaled-down or ‘basic’ SEA which could, as part of the methodology, focus on water. There was a belief that ‘... the SEA is probably one of the most critical and useful tools’, to promote cross-sectoral working (Interview 7).

Interpreting the extent of functional co-ordination for water resource management in Johannesburg, unlike in the other three metros, had to take note of the organisational configuration of the city’s administration. The city’s plan for organisational restructuring, iGoli 2002, saw the creation of new institutional structures, a core administration with regional administrations, and corporatised entities (City of Johannesburg Council, 2001: 53). The corporatised service delivery agency model, referred to as municipal owned entities or ‘state owned companies’, includes utilities (e.g. water-related services) rendering specific services through service delivery agreements with the city (City of Johannesburg Council, 2001: 94 and 95). These agencies are responsible for planning, design and implementation of services and the management of associated assets where the municipality, through its core administrative departments, retains responsibility for monitoring the performance of the agencies (City of Johannesburg Council, 2001: 107).

Although the SOEs report to a board of directors, the council is the only shareholder. The SOEs are held accountable to the city through service delivery agreements. The city’s core administrative departments oversee the performance of the SOEs through setting policy, outcomes, and standards. The company boards and management of the SOEs have relative autonomy in carrying out their activities. The core departments in the municipality have an oversight function to ensure that the SOEs comply with departmental objectives (CoJ, 2011: 17, 18). This arrangement, in comparison with the other metros, introduces greater complexity in how departments interact both vertically and horizontally around cross-cutting policy issues, such as WSUD.

For example, and in contrast to the other three metros, the city has combined environmental management with water and sanitation in the form of an Environment, Infrastructure and Services department, which oversees the delivery of water and sanitation by Johannesburg Water, an SOE. Sitting astride this department is the Department of Transportation which, along with the Johannesburg Roads Agency, are formally responsible for stormwater policy and implementation. The JRA (an SOE) is involved in planning, designing, constructing, operating, controlling, rehabilitating and maintaining the city's roads and stormwater infrastructure (CoJ, 2011: 29).

Although this arrangement can, on face value, result in greater vertical fragmentation (see organisational chart in Appendix 4) in the service delivery chain, in comparison to horizontal fragmentation (where environmental management and W&S are at least combined), the arrangements for stormwater do exhibit horizontal fragmentation. For example, advocacy for the application of SuDS principles, especially in stormwater, appears to be driven by the Environmental Management department, which, together with JRA, is directly involved in the development of a stormwater manual. Jurisdictionally, the Department of Transportation is responsible for setting stormwater policy, with the JRA drafting and implementing stormwater guidelines. This arrangement has thus far resulted in an 'implicit' acceptance of SuDS principles and, with respect to stormwater in particular, an as yet incomplete revised stormwater manual, where JRA holds the budget and Environmental Management has assumed the mandate to explicitly enforce SuDS principles[9] (Interview 14).

B5.2.2 Co-ordinated service-level responses to WSUD (more extensive interaction)

Despite the indications of limited co-ordination across water services and related functions in the four metros, there were examples of more extensive co-ordination, including through formalised channels.

In Cape Town, the approach of the Roads and Stormwater Department (RSD), driven by its Catchment, Stormwater and River Management section (CSRM) in particular, is relatively more encompassing of trans-disciplinarity in urban water management, and sees its role as 'influencing' other line functions (Interview 3). This is evident in the publication of a Management of Urban Stormwater Impacts Policy. This policy refers to WSUD principles in urban planning and water management, and in particular the adoption of SuDS (CoCT, 2009d: 3; Haskins, 2012). The city aims to employ SuDS to support a 2005 by-law relating to stormwater which prohibits discharge of anything other than stormwater into the stormwater system to ensure its protection (clause 3 and 4 of the by-law). This is further supported by

[9] A Terms of Reference for the revision of the city's revised stormwater manual has been drafted, and a budget allocated, and the initiation of the project was awaiting the go-ahead of the JRA (Interview 14).

introducing measures for improving natural water sources, as part of the stormwater system, and stemming the deterioration of these water assets (CoCT, 2009d: 7). In this regard the city's Department of Environmental Resource Management (ERM) is also directly involved in commenting on proposed stormwater designs received by CSRM (Interview 2). The CSRM section also explained that it convenes an inter-departmental 'Inland and Coastal Water Quality Committee'. Although it does not explicitly act as a WSUD vehicle, the committee otherwise represents a nascent (18 months) yet formal platform for interacting with other line functions[10] to discuss the health of the city's natural water resources, which is driven by a strategy of the same name (Interview 3).

In eThekwini, the municipality's Catchment Management section also cites a number of WSUD-related interventions such as regulations governing the extent of development adjacent to or in floodplains, stormwater guidelines requiring attenuation[11] and encouraging rainwater harvesting, the aforementioned Green Rivers initiative, as well as project-based interventions to enhance co-ordination across line functions (Interview 5; eThekwini, 2012). In the latter case, promoting cross-sector co-ordination appears to have been spurred by localising water resource management to a catchment level, with the catalyst being a partnership between eThekwini municipality and the German city of Bremen that focuses on the uMhlangane river catchment area. The catchment was also selected because it contains diverse settlement and land use activities: rural area, high density urban township, medium and low density housing, industrial area, and transport corridor. A major initiative in the catchment is the Sihlanzimvelo project, in which local residents are formed into cooperatives to maintain the health of the streams in exchange for employment, which has also enabled the city to contribute to the national government's Expanded Public Works Programme. Improving cross-sector co-ordination was also a key driver behind the initiative, with the observation that a variety of line functions (seven or eight[12]) were carrying out specialised stream maintenance activities along the same water courses. The project attempts to directly involve local people in stream maintenance which used to be carried out by various line functions, although the latter perform oversight and retain overall responsibility. The initiative is directly overseen by consultants and is co-ordinated by the Roads and Stormwater Maintenance section (Interview 5; eThekwini, n.d.)

More extensive levels of co-ordination were also evident in Tshwane's Integrated Stormwater Planning (ISP) section, in the Department of Transport and Roads. The ISP, through its advocacy of SuDS in the design of stormwater infrastructure, has tried to lobby for the adoption of alternative stormwater provision, especially amongst private developers. Similar to the cities of eThekwini and Cape Town, the ISP section also carries out a catchment management function, including river maintenance, although given the backlog and lack of

[10] These include Roads and Stormwater, Catchment, Stormwater and River Management, Water and Sanitation, Solid Waste, Environmental Resource Management, Sports and Recreation, and Health

[11] This is cited by the municipality as an example of 'SuDS', referring specifically to a stormwater management policy requiring that SuDS is in place (eThekwini n.d.) This policy is being overseen by the Coastal, Stormwater and Catchment Management section.

[12] Functions included litter picking, alien plant removal, indigenous planting, water monitoring, erosion control and culvert cleaning

financial resources, coupled with severe understaffing (3 posts filled of 14), this stretches the available capacity of the section (Interview 9). Despite these constraints, there appeared to be a close level of co-ordination between ISP and other line functions pertaining to the effects of stormwater drainage on natural water courses. This was in the form of a Critical Stormwater Maintenance Framework, consisting of a committee including Environmental Management, Stormwater, and the provincial department of environment.

The ISPs involvement in river maintenance also appeared to be 'jointly' managed with Environmental Management, addressing issues such as sedimentation, siltation and flooding, prompting the suggestion that the city could contemplate the creation of a structurally-integrated 'watercare management department', which brought together the roles of ISP and Environmental Management to address problems such as silt build-up in the stormwater system (Interview 9). Elsewhere in Tshwane, it was noted that a 'forum' had been created which brought together the stormwater, environmental management and city planning sections to discuss and comment on development applications – although the absence of strong SuDS guidelines with policy and legislative backing minimised the effectiveness of this interaction – in comparison to other fora focusing on issues such as Environmental Impact Assessments (Interview 13).

Despite organisational arrangements which exhibit horizontal fragmentation in stormwater management in Johannesburg, there is evidence of co-ordination mechanisms which might mitigate the risk of jurisdictional constraints. This involves principals in the departments of Environmental Management and Transportation being driven by a mutual interest to engage and interact at a practical level, or for the officials in the former department to 'make friends', as one official put it, on stormwater issues with their colleagues in Transportation, which sets policy for stormwater. The Department of Transportation is also trying to incorporate WSUD-related SuDS principles into planning new initiatives such as the 'Complete Streets' project to re-design and re-proportion the city's road reserves. Moreover, Transportation has also signalled its interest in building in SuDS and WSUD principles into stormwater implementation by the JRA, but given the city's de-centralised agency model which limits the department's role to oversight, the challenge is translating these principles into 'measurable' outputs, or holding the JRA to account via performance measurement processes which function on the basis of 'indicators' and 'scorecards' (Interview 12). For instance, it was observed that the 'key performance indicators' being used by the JRA for private developments do not currently take into account alternative stormwater designs or methods (Interview 14; 15). Despite this, and without the aid of an approved revised stormwater manual, the JRA has adopted a more pragmatic[13] and case by case approach to recommending and advising the use of low impact stormwater designs depending on the size and geographical features of sites.

Finally, the level of informal horizontal co-ordination between the Environmental Management and Transportation departments also appears to be receiving support up the

[13] This was also described as one in which the city will 'do it where we can but it's not our core business' (Interview 14).

hierarchy, where the executive directors of the departments are said to have identified the need to discuss stormwater issues in particular (Interview 12). This level of informal co-ordination may also be supported by the formal 'clustering[14]' of departments in the city, which includes, *inter alia*, the Environment, Infrastructure and Services department and the Transportation[15] department, together with their SOEs, in a 'Sustainability' or 'Sustainable Service' cluster (CoJ, 2012a: 32-33; CoJ, 2012b). The potential benefit of the clusters was ascribed to their role as a 'clearing house', which could act to sync line functional business plans; as well as enabling a form of accountability through acting as a 'check' on individual departments and to determine 'who needs to do what', including through resource allocation (Interview 14; 16). It was also evident that the existence of the cluster could partially compensate for WQCM's lack of direct oversight, through the hierarchy of the Environment and Infrastructure Services department, over water related agencies such as JRA, which is overseen by the Department of Transportation.

[14] The city intends to develop templates for reporting on oversight which will have to pass through the clusters for comment, which includes departmental senior managers, before reaching the political level. It isn't clear how this will directly affect efforts to co-ordinate different departments and agencies on specific policies and programmes.

[15] It was elsewhere mentioned that the Transportation department was yet to be allocated to a cluster (Interview 12)

B6 Summary of enablers and challenges to promoting coordination and integration in water services

B6.1 Enablers to facilitate greater coordination & integration

- Increasing emphasis on re-use.
- Increasing sensitivity to monitoring water quality.
- Strategic clustering of functional activities within metros can potentially spur on more substantive co-ordination and integration of water services.
- Protection of urban catchments (i.e. spatial focus) can facilitate functional co-ordination.
- Existence of auxiliary structures, e.g. those additional to traditional line function structures, such as special forums and committees, can potentially facilitate co-ordination and integration.

B6.2 Challenges facing greater coordination & integration

- Cost-recovery demands/pressures of water and sanitation (reticulation services) can hinder the pace of co-ordination and integration with other water services functions.
- Syncing planning at a city-wide level (e.g. strategic, spatial) with infrastructure planning being carried out at a line-function level (e.g. in water services departments).
- Delays in finalising planning and regulatory instruments with legal force can inhibit the potential for cross-departmental co-ordination and integration.
- Advocating WSUD principles in policies aimed at retro-fitting existing settlements, especially those targeted for municipality-financed low-cost housing will be confronted by challenges of density, scale of demand and political sensitivities concerning the perceived quality of the engineering options it represents.

B7 Conclusions

Findings from a review of the institutional responses to WSUD in four metropolitan local governments has revealed that the multi-faceted nature of the concept has to distinguish between cities responding to individual principles of WSUD, and the extent to which various line functions co-ordinate or integrate their responses. It was evident that all four metros are responding to the various individual components of WSUD; although it was also clear that a co-ordinated response to WSUD appears to be situated towards the more limited end of the spectrum, in terms of the extent and nature of interaction. It was also evident that there was unrealised potential for more extensive co-ordination, which could be facilitated by urban and strategic planning fora. In addition, there were also examples of tangible and realisable co-ordination of a more extensive kind, which appeared to be driven by the stormwater (through catchment management), as well as environmental management portfolios. This corresponds with the incorporation of an environmental focus in the stormwater management function in three of the metros (see section 3 of this report), along with efforts to diversify the skills make-up and emphasise new skills through re-training in stormwater / catchment management functions.

Despite concrete efforts driven from stormwater and environmental management to try to co-ordinate various line functions to manage urban water resources, a number of constraints continue to impede the full potential of these efforts. One of these constraints is the need to ingrain SuDS principles as a vehicle or prerequisite to promote the more ambitious and multi-faceted agenda of WSUD. For example, in Tshwane, the ISP section acknowledged that the absence of an enabling council-approved stormwater policy and guidelines (with the force of a by-law) which were, in addition, relevant to local conditions, reduced their ability to 'enforce', *ex ante*, SuDS principles as opposed to advocating for them in 'reaction' to (or in a reactive manner) the proposals presented by private developers[16]. Officials did however acknowledge that despite this shortcoming, and in order to put in place a viable set of guidelines supported by policy, the city required 'data', or actual experience of putting SuDS principles into effect on the ground (Interview 9). In Johannesburg, despite efforts to mitigate the effects of vertical fragmentation through informal and clustered horizontal co-ordination, the application of SuDS was also said to be hampered by the need to develop a stormwater policy and re-formulate existing manuals to explicitly advocate design based on these principles (CoJ, 2012b). This could also help to focus and strengthen the enforcement of existing stormwater by-laws which were characterised as 'general' and 'open-ended'[17] (Interview 12; Interview 15). Moreover, the need for interventions to effectively re-train (capacity-build) technical officials on sustainable drainage approaches was also mentioned as part of Johannesburg's attempt to revise its stormwater manual (Interview 14).

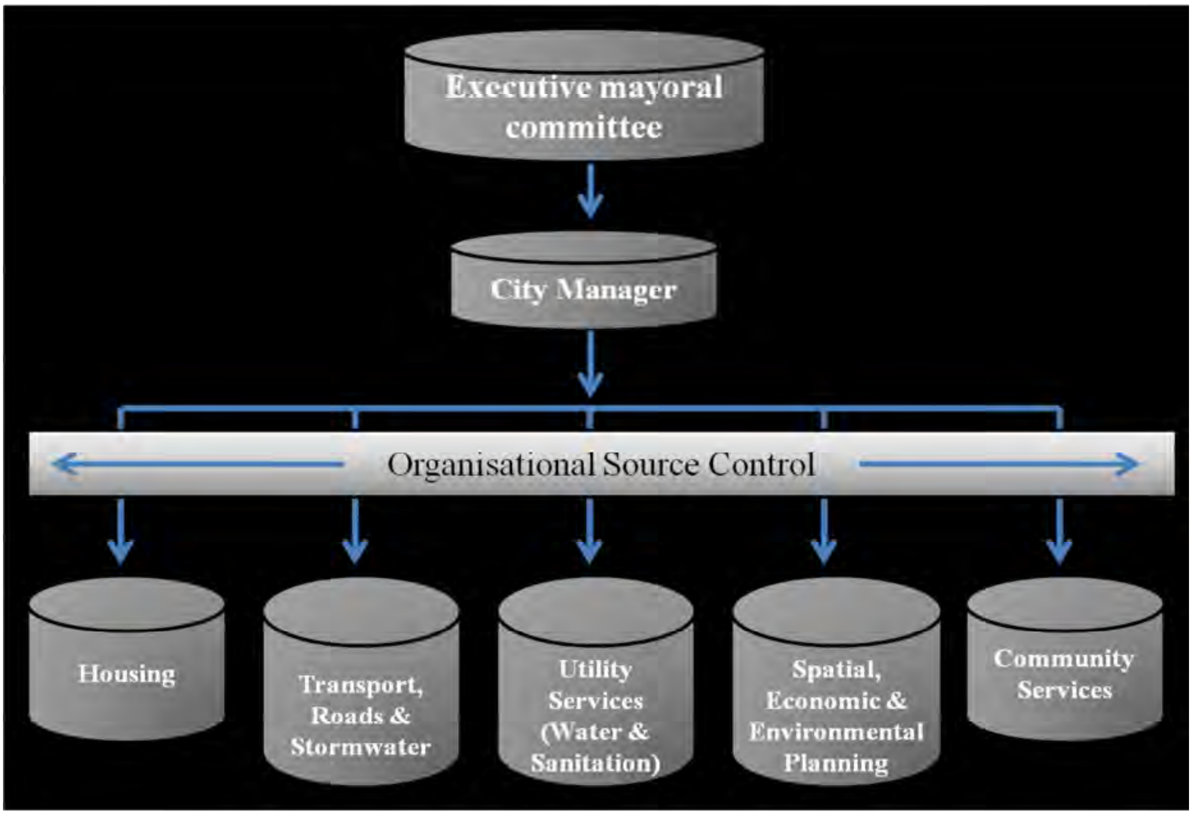
[16] This was also evident in Johannesburg, where private developers appeared to be generally motivated by quick, easy and cost-effective solutions to stormwater designs (Interview 15)

[17] It appears that a revised stormwater manual allowing for alternative designs incorporating SuDS principles is currently pending approval by the board of the Johannesburg Roads Agency.

Even where official stormwater policy has incorporated SuDS and WSUD principles, such as in the Management of Urban Stormwater Impacts Policy in Cape Town (CoCT, 2009d: 8), the application of these principles has been more easily accomplished in privately-financed developments, and in greenfield sites, in comparison with city-driven developments, where retro-fitting infrastructure assets can be a disincentive for other line functions such as Roads and W&S (Interview 2; Interview 3). Officials also noted that making inroads into brownfield sites, which included existing low-cost housing developments, as well as planned new developments, also presented a challenge for WSUD due to the scale of demand, the related 'political sensitivity' of the issue, and the perceived quality of the engineering option it represents (Interview 2; Interview 9; Interview 12).

Finally, this reinforces earlier references to the need for policy advocacy of SuDS and WSUD at a supra-management or executive level, which could also facilitate political backing. Having said this, the policy branding of WSUD is relatively low and, tactically speaking, it may be more effective for metros to push WSUD as part of complementary initiatives that have greater and wider public and policy appeal, such as 'greening' initiatives which promote energy efficiency, as well as climate change mitigation.

B8 Typical organisational arrangements for WSUD-related line functions in South Africa



Source: (Armitage *et al.*, 2012)

B9 List of interview participants

Name	Title	Department	Municipality
Geoff Tooley	Manager	Coastal, Stormwater & Catchment Management	eThekwini
John Harrison	Engineer	Water and Sanitation	eThekwini
Bill Pfaff	Engineer	Water and Sanitation	eThekwini
Helene Epstein	Senior Manager	Development Planning, Framework Planning Sub-division	eThekwini
Cameron McLean		Environmental Management Department, Environmental Planning Unit	eThekwini
Liezel Kruger-Fountain	Principal Professional Officer	Spatial Planning and Urban Design Department	Cape Town
Pat Titmuss	Regional Manager	Department of Environmental Resource Management, Environmental and Heritage Management	Cape Town
Morne Theron	Senior Environmental Professional	Department of Environmental Resource Management	Cape Town
Candice Haskins	Senior Professional Officer (Aquatic Ecology)	Roads and Stormwater Department, Catchment Stormwater and River Management Branch	Cape Town
Rod Arnold	Head	Roads and Stormwater Department, Catchment Stormwater and River Management Branch, Strategy and Specialist Support	Cape Town
Christiaan A Etsebeth	Engineering Consultant	Transport Department, Transport and Infrastructure Planning Section, Integrated Stormwater Planning Sub-section	Tshwane
Gawie Jansen van Vuuren		Transport Department, Transport and Infrastructure Planning Section, Integrated Stormwater Planning Sub-section	Tshwane
Pieter Odendaal	Deputy Director	Transport Department, Transport and Infrastructure Planning Section, Integrated Stormwater Planning Sub-section	Tshwane

Name	Title	Department	Municipality
Frans Mouton	Director	Water and Sanitation	Tshwane
Lodie Venter	Planning Professional	City Planning and Development Department	Tshwane
Francis Naude		City Planning and Development Department, Regional Planning	Tshwane
Marius Nadel	Acting Manager	City Planning and Development, Strategic Projects	Tshwane
Nomugya Kisuule	Deputy Director	City Planning and Development Department, Metropolitan Planning	Tshwane
Jane Eagle	Assistant Director	Environmental Management Department, Open Space Planning, Natural Resources Directorate	Johannesburg
Ian Boyd	Deputy Director	Department of Transport, JRA Compliance	Johannesburg
Ilse Kotze	Deputy Director	Environmental Policy and Resource Management, Environmental Regulatory Services	Tshwane
Antoine Minnar		Environmental Policy and Resource Management, Environmental Compliance and Enforcement Sub-section	Tshwane
Rudzani Mukheli	Deputy Director	Environmental Policy and Resource Management, Environmental Impact Management	Tshwane

B10 Interview schedule

i) A working definition of Water Sensitive Urban Design (WSUD) follows; to what extent does this conform to your understanding of WSUD?

> ***WSUD** generally refers to the **integration** of urban planning with the management, protection and conservation of the urban water cycle that ensures that urban water management is sensitive to natural hydrological and ecological processes. It is also encompassed in the concept of **Integrated Water Resources Management (IWRM)**, or a process which promotes the **co-ordinated** development and management of water, land and related resources.*

ii) Have WSUD principles been included in the metro's **policies** relating to the delivery of water and sanitation, stormwater and wastewater management? *If yes, please describe.*

iii) To what extent has your metro implemented WSUD principles?

iv) What type of resources do you need to implement WSUD?

v) Can you describe the organisational arrangements & reporting lines for:

- delivery (water and sanitation)
- wastewater management
- stormwater management

vi) Please describe the cycle of how the Metro manages water from source to delivery.

vii) Do existing organisational arrangements for the delivery, wastewater and stormwater management facilitate or hinder the implementation of WSUD? *Please elaborate.*

viii) What role has the urban planning function traditionally played in delivery, wastewater, and stormwater management in the metro?

ix) How transferable is the concept of WSUD to the service delivery context in which the Metro operates, e.g. backlogs, free basic services, and extension of services.

x) To what extent is WSUD a priority for:

- delivery (water and sanitation)
- wastewater management
- stormwater management

xi) What type of support is the metro receiving from national government to promote WSUD?

B11 Organisational diagrams

<u>City of Cape Town</u> (This is a composite diagram produced by consulting several sources, including City of Cape Town, 2011c: 95; City of Cape Town, 2011d: 86; City of Cape Town, 2009d: 4; and documentation from the Catchment and Stormwater branch)

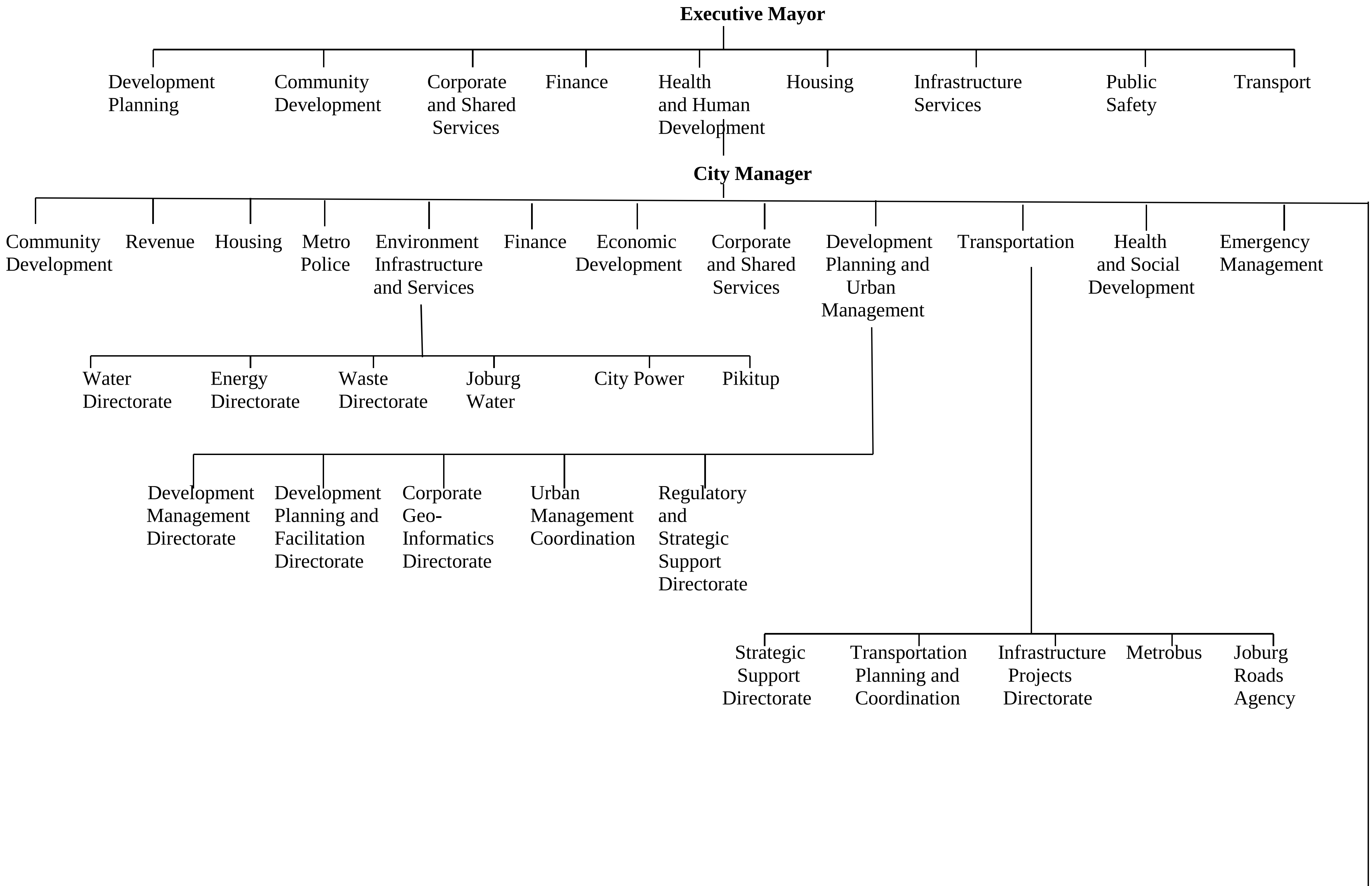
- **City Manager**
  - **Utility Services**
    - **Water and Sanitation**
      - **Bulk Water**
      - **Waste Water Treatment**
      - **Reticulation**
        - **Water**
        - **Sewerage**
      - **Water Demand Management Strategy**
    - Electricity Services
    - Solid Waste Management
    - Service Regulation and Logistics
  - **Transport, Roads and Stormwater**
    - **Roads and Stormwater**
      - **Catchment, Stormwater and River Management Branch**
        - Roads Division
    - Transport
    - IRT Implementation
    - IRT Operation
    - Strategic Support
  - Corporate Services
  - Finance
  - Safety and Security
  - Community Services
  - Health
  - Human Settlement
  - Tourism, Events and Marketing
  - Social and Early Childhood Development
  - Economic, Environmental and Spatial Planning

eThekwini Municipality (eThekwini Municipality, 2011: 20)

City Manager

- Deputy City Manager Sustainable Development and City Enterprises
  - Development Planning, Environment and Management
  - Economic Development & Investment Promotions
  - Business Support, Markets, Durban Tourism
- Deputy City Manager Procurement and Infrastructure
  - Supply Chain Management
  - Housing
  - Electricity
  - Water and Sanitation
  - Cleansing and Solid Waste
  - Engineering
  - Transport Authority
- Deputy City Manager Safety and Security
  - Metropolitan Police
  - Fire and Emergency Services
  - Disaster Management and Emergency Control
  - Security Management
  - Corporate Investigations
  - Safer Cities and iTrump
- Deputy City Manager Health and Social Services
  - Health
  - Parks, Recreation and Culture
- Deputy City Manager Governance
  - City Hall, Administration and Secretariat
  - Communications
  - Regional Centres
  - Community Participation
  - International and Governance Relations
- Deputy City Manager Corporate and Human Resources
  - Human Resources
  - Skills Development
  - Management Services and Organisation Development
  - Occupational Health and Safety
- Treasury

<u>City of Johannesburg</u> (This is a composite diagram produced by consulting City of Johannesburg, 2011: 15, and the descriptions given by individual directorates as posted on the City's homepage: www.joburg.org.za/depts)



Office of the Executive Mayor

- Central Strategy Unit
- Chief Information Officer
- Internal Audit and Risk
- Legal Compliance
- Municipal International and Intergovernmental Relations
- Office of the City Manager
- Private Office of the Executive Mayor
- Public Liaison

<u>City of Tshwane</u> (City of Tshwane, 2011: 24-25, 46)

- **City Manager**
  - **Service Delivery Coordinator**
    - **Strategic Executive Directors**
      - Finance Department
      - City Planning and Economic Development Department
      - **Public Works and Infrastructure Development Department**
        - **Water and Sanitation Division**
        - Electricity Division
      - Social Development Department
      - Agriculture and Environmental Management Department
      - Housing and Human Settlement Department
      - **Transport and Roads Department**
        - **Roads and Stormwater Division**
        - Transport Development Division
      - Corporate and Shared Services Department
      - Sport, Recreation, Arts and Culture Department
      - Community Safety Department