Chapter 2
What Are the Main Options for Applying the Multiple-Use Water Services Paradigm?

Abstract This brief asks the question, what are the main options to apply the MUS paradigm in urban environments? It breaks down the various components and provides cost–benefit analyses for the various components along with challenges and considerations for both the short and long terms. The brief includes a section on the MUS approach and a means to calculate the value of MUS systems, as well as provides tools and resources to support urban blue-green design. Comprised of actual and potential options for decision makers and policy makers to integrate blue and green measures that target the optimal synergies between interventions and techniques with the purpose of delivering multiple benefits, reproducing the natural pre-development process to the best possible degree and boosting ecosystem services.

Keywords ESS · Green roof · Green walls · Infiltration trench · MUS · MUSIC · Permeable pavement · Rain gardens · Retention ponds · Swales · SWMM · Urban agriculture · Urban water management · UWOT · WASP

1 Introduction

An overview of main concepts and techniques for achieving the envisaged MUS synergy in urban design and management is presented in Fig. 1 and analysed in detail in the following sections.

2 Wastewater Reuse and Recycling

Wastewater reuse—recycling can be generally defined as the use of treated water for several purposes such as toilet flushing, landscape irrigation, groundwater recharge, etc. Wastewater is a general term for used water that its quality has been affected from human activities, residential, commercial or industrial. Wastewater is usually discharged through centralised sewer systems to Wastewater Treatment Plants for removal or reduction of hazardous substances. Alternatively, wastewater

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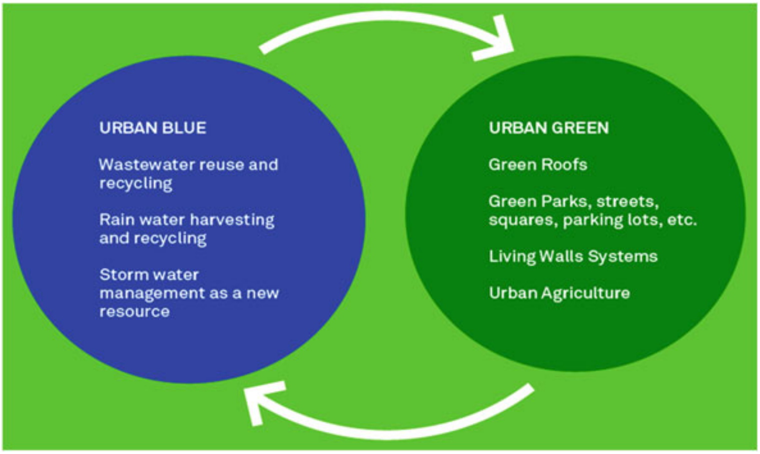


Fig. 1 The main options for multiple-use water services paradigm

can be treated on-site. The term 'reused' water is often used similarly with 'recycling' water or 'reclaimed' water.

Residential wastewater, based on the source and level of contamination can be further classified as black (highly polluted) and grey. Black water, usually referred to as wastewater, is highly contaminated water coming from toilets and urinals. Grey water, on the other hand, is less polluted water discharged from sinks, showers and bathtubs, washing machines and drinking fountains. When reusing grey water, water discharged from kitchen sinks and dishwashers is generally excluded due to higher levels of contamination coming from food residues and animal products. MUS mainly focuses on the on-site use of reclaimed grey water used for multiple non-potable purposes such as indoor and outdoor plant irrigation, including green roofs and walls, and toilet flushing.

2.1 What Are the Main Components and Costs Related to Grey Water Reuse?

Grey water reuse systems can vary significantly from simple, low-cost appliances that harvest grey water and convey it for direct use, e.g. in toilets and gardens, to composite systems integrating specialised treatment processes.

Cost and energy required can also vary, mainly increasing as more and better treatment is involved. Grey water reuse systems are more suitable for new-built developments, as retrofitting existing systems can be more expensive, but they can be incorporated while renovation and plumbing replacement activities occur (CGBC 2011).

Lookout Grey water policies and proper regulation are of key importance to reinforce public acceptance and awareness, economic viability and implementation of grey water reuse practices, aiming at reducing water demand and improving water sustainability (Yu et al. 2013). Economic incentives, such as subsidies, provided by water utilities can be valuable tools to promote grey water reuse technologies. Tucson Water, in the city of Tucson, Arizona, through the Gray Water Rebate Program offers rebates up to $1,000 per household for the installation of grey water irrigation systems for both retrofits and new buildings (www.tucsonaz.gov/water/rebate).

2.2 *Why Grey Water Recycling?*

- Reduction of water demand from public water supply for non-potable uses, leading both to lower household water bills and wider community benefits.
- Reduction of effluent discharge and thus energy reduction for wastewater treatment.
- Household water savings can reach a level of 50 % through grey water reuse for toilet flushing and garden irrigation (Maimon et al. 2010).

3 Urban Green Spaces

Green spaces in the cities include private gardens, parks, green parking lots, squares and streets, community forests, etc.

3.1 *What Is the Cost-Benefit?*

Planting and maintaining trees and vegetation can be costly. The main costs associated include initial planting and ongoing maintenance, such as for irrigation, pruning and pest control, administration, etc. Nevertheless, the benefits derived (direct and indirect) can exceed the overall cost.

Facts A study on the functioning and value of street and park trees in five US cities from different States (McPherson et al. 2005) showed that for every dollar invested in tree planting and ongoing maintenance, benefits returned annually ranged from $1.37 to $3.09. More specifically annual costs ranged from around $15–$65 per tree, while total revenues including energy savings, atmospheric CO_2 and storm water run-off reduction, air quality, aesthetics and other benefits were about $31–$89 per tree. Regarding costs, pruning was

Table 1 Benefits of rainwater harvesting

Short-term benefits	Long-term benefits
Meet water demand when no other water sources are available	Reduced storm water run-off leading to lower energy consumption for storm water treatment
Reduction of water demand	Use of harvested rainwater for aquifer recharge and increase of depleted groundwater table
High collection and distribution efficiency	Reduction of diffuse pollution resulting in improvement of aquatic ecosystems
Self-sufficiency (less dependency on distant watercourses)	Potential for lower consumer water bills
Reduction of flood risk (reduction of economic losses)	Greater flexibility of a decentralised system consisting of numerous water resource points in case of a natural disaster rather than a centralised water supply system that may collapse or go out of order
Enhance rational utilisation of water through decentralised systems	

found to be the most expensive practice, with related costs to be around 25–40 % of the total annual cost, followed by administration and inspection costs (8–35 % of total annual costs), while tree planting cost was estimated to be 2–15 % of total annual urban forestry expenditures.

4 Rainwater Harvesting

Rainwater harvesting (RWH) is a decentralised technique of collecting and storing rainwater for later use at or near the point where water is needed or used providing multiple benefits (Table 1). Depending on scale, requirements and purpose, RWH systems can range from low storage capacity (50–100 gallon) systems (e.g. rain barrels) to larger systems (1,000–100,000 gallons) (US EPA 2013). Rain barrels can be easily placed outside buildings, with no connections to internal or external plumbing, where rooftop run-off from downspouts is captured for later use mainly for outdoor purposes, such as car washing and irrigation. Higher volume systems (e. g. cisterns) collect storm water from roofs and other surfaces (e.g. parking lots, terraces), and after quality treatment provide water to a distribution system. Harvested water can be used outdoors (e.g. landscape irrigation, fountains) or indoors (e.g. toilet flushing, clothes washing).

A typical RWH system is mainly comprised of the catchment area upon which the rain falls; storage tanks and cisterns; gutters and downspouts to transfer rainwater from the catchment area to the storage system; a filtering system to remove debris, solids and other materials; a monitoring system (e.g. for monitoring the water level inside the tank) and a system to convey water for further use (e.g. gravity system or pumps). The main issues emerging when constructing an RWH

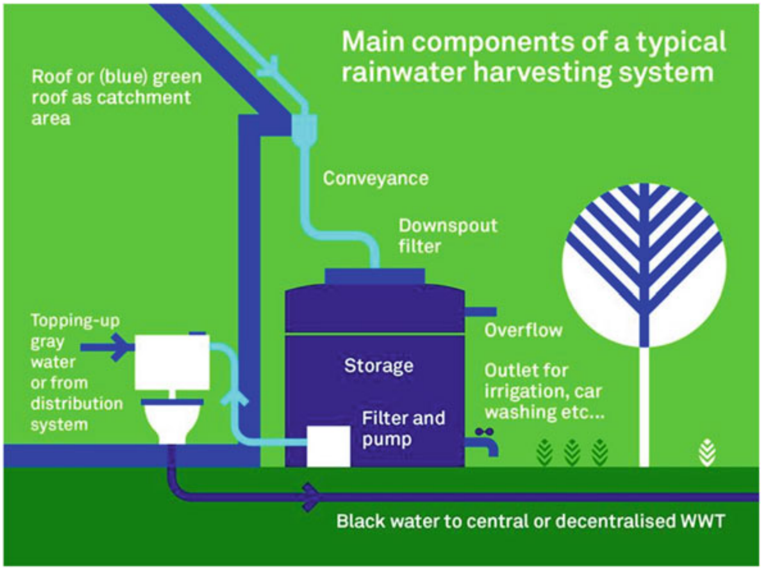


Fig. 2 Main components of a typical rainwater harvesting system

system are the availability and cost of materials; labour cost; space availability; local expertise for the construction of the system; consideration of local traditions on water storage; climate conditions and catchment characteristics (Fig. 2).

4.1 New Build Versus Retrofit

Rainwater harvesting can be applied in most buildings but it is more suitable for new constructions due to the fact that the installation of an underground tank could be very expensive and may involve re-routing of some services as well as fitting a tank and filter in an existing drainage scheme will involve changes in the pipe system (CGBC 2011).

4.2 What Is the Cost?

The cost of an RWH system is site-specific and varies significantly depending on size, type and complexity of the system. The cost of a rain barrel can differ based on material and size, with a typical 50-gallon, plastic rain barrel to cost around $70 (US EPA 2013). For larger systems that do not have significant filtration or

Table 2 Maintenance activities and costs associated with cisterns

	Months between events	Cost per event	Total cost per year
Routine maintenance activities			
Inspection, reporting and information management	6	$130	$260
Roof washing, cleaning inflow filters	6	$240	$480
Corrective and infrequent maintenance activities (unplanned and/or >3 years between events)			
Intermittent system maintenance (system flush, debris/sediment removal from tank)	3	$390	$130
Pump replacement	5	$989	$198

Source WERF (2009)

distribution requirements, storage is usually the most expensive element. A cistern can cost around $1.50–$3.00 per gallon of storage. The more complex the system, the higher the capital cost. Filtering, pumping, distribution and treatment systems, plumbing and drainage connections, excavations, installations and other elements can have an additional cost of around $2–$5 per gallon (Table 2).

5 Green Roofs and Green Walls

5.1 What Are Green Roofs?

A green roof, also known as eco-roof, living or vegetated roof, is a roof of a building that is entirely or to an extent covered with vegetation planted over a waterproofing membrane. Green roofs can be categorised, depending on the depth of planting medium and level of maintenance they need, as extensive, semi-intensive and intensive (Fig. 3).

A typical green roof is a complex system of several layers of materials to attain waterproofing and to remove water from the roof deck (Tolderlund 2010; Fig. 4).

5.2 What Are the Risks and Costs Associated with Green Roofs?

In case of bad construction or inefficient maintenance, a green roof may face the risk of leakage and damage or even collapse, or may fail to deliver the desired energy efficiency levels. The main factors affecting the cost of green roofs include the type of structure (extensive or intensive), types of vegetation, irrigation systems, accessibility, retrofit or new development. Generally, an intensive green roof has a higher capital and maintenance cost than an extensive green roof, as well as

	Extensive	**Semi-Intensive**	**Intensive**
			
Depth of growing medium	3 - 5 inches	5 - 7 inches	7 - 24+ inches
Weight max.	15- 25 lbs/ft^2	25- 40 lbs/ft^2	35 - 80+ lbs/ft^2
Plants	sedums, small grasses, herbs and flowering herbaceous plants	selected perennials, sedums, ornamental grasses, herbs and small shrubs	perennials, lawn, shrubs and small trees, rooftop farming
Irrigation	Not recommended	Occasional irrigation	Advanced irrigation systems
Maintenance	low	medium	high
Use	Living machine	Diversity, habitat	Garden, park
Costs	low	medium	high

Fig. 3 Types of green roofs (*Source* Adapted from http://www.greenrooftechnology.com)

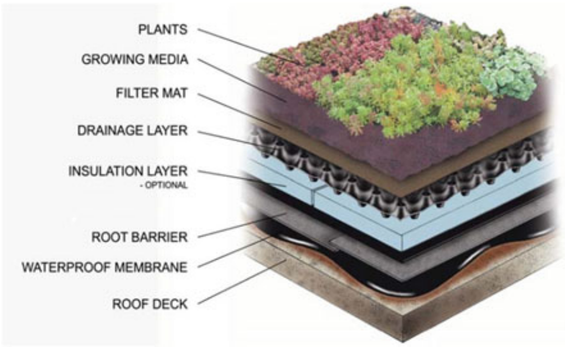


Fig. 4 Typical green roof layers (Photo courtesy American Hydrotech, Inc. *Source* Tolderlund (2010))

installing a green roof in a new construction costs less than retrofitting (Peck and Kuhn 2003). The installation of an extensive green roof with root repellent/ waterproof membranes may cost around \$10–\$24 US/sq.ft. (GRHC 2014). Green roofs are more expensive to construct than conventional roofs but they can be more cost-effective in the end due to extending the life span of the roof membrane and leading to significant energy savings from heating and cooling.

Fig. 5 A green wall (*left*) and a green façade (*right*) in Melbourne (*Source* DEPI (2014))

Facts A 2006 study conducted by the University of Michigan compared the costs and benefits, including storm water management and public health improvement, of a 21,000 sq.ft. green roof over a conventional roof. The results showed that the installation of the green roof would cost $464,000, while the conventional one $335,000 (in 2006 values). However, it was estimated that the green roof would save more than $200,000 during its lifetime, with two-thirds of that savings resulting from reduction in energy needs (Clark et al. 2008a, b).

5.3 What Are Green Walls?

Green walls, also known as living walls, bio- or eco-walls are vertical plants either grown on freestanding structures or attached to interior or exterior walls (DEPI 2014). They are composite systems incorporating plants, growing medium, drainage, irrigation and often fertilisation. They can retain a great variety of vegetation depending on local climatic conditions. In green walls, the whole structure is plated compared to **green façades** where climbing plants are used, which are either rooted in the ground at the bottom of the structure or are planted in boxes at different levels and cover a part or the entire surface of a building. However, green wall is a general term used for interior or exterior vertical vegetated surfaces (GRHC 2014). They are usually designed for aesthetic purposes but they can provide additional benefits such as enhanced interior and exterior air quality, thermal insulation and higher property values (Fig. 5).

5.4 Green Walls Used for Wastewater Treatment

Water recycling systems can be linked to green walls, pumping the captured grey water (or even collecting storm water), which then passes through gravel filters and marine plants for treatment. The effluent is then directed to a storage tank for domestic use or to public water treatment plants (GRHC 2014).

Showcase: EDITT Tower in Singapore

Photorealistic image of the EDITT Tower in Singapore, designed with a grey water filtration system that includes water purification, water and wastewater recycling. Only 45 % of building water demand is supplied through the public mains.

Source TR Hamzah & Yeang Sdn Bhd (http://www.trhamzahyeang.com/project/skyscrapers/edit-tower01.html)

5.5 What to Consider Before Applying Green Walls and Façades?

While selecting a green wall system one must consider installation and maintenance cost and structure requirements, climate conditions, lighting, types of plants and quality, functionality and lifespan (DEPI 2014). A successful construction must serve its design purpose, require low maintenance, effectively support the selected vegetation and have a long lifespan.

5.6 Why Green Roof and Green Wall Systems?

Mitigation of Urban Heat Island Effect—Reduced air temperature through shading, evaporation and light absorption provided by plants.

Enhanced air quality by capturing airborne pollution, harmful gases and volatile organic compounds and providing thermal insulation inside buildings resulting in reduced energy demand for heating and thus less CO_2 released into the air.

Increased biodiversity in an urban environment—Green roofs and walls can sustain a range of vegetation and serve as habitat and nesting place for different bird species.

Local job creation in the fields of design, manufacturing, installation and maintenance.

Enhanced aesthetics, amenities and recreational green spaces (e.g. community gardens, playgrounds in green roofs) and *increased property values of buildings.*

Storm water retention and water filtration through green roofs—Green roofs can return 50 % of annual precipitation back to the atmosphere through retention and evapotranspiration (Berghage et al. 2009). In addition to reducing the volume of storm water run-off, a green roof can successfully delay the time to peak, leading to less stress on sewer systems at peak flow periods.

Thermal insulation and energy savings—In summer, an extensive green roof can reduce daily energy demand for air conditioning during summer by 75 % (Liu and Baskaran 2003).

Noise reduction—Vegetated vertical and horizontal surfaces can block high-frequency sounds and when combined with a substrate or growing medium can block low-frequency sounds. Extensive and intensive green roofs can reduce sounds from outside the building by 40 and by 46–50 decibels, respectively (Peck et al. 1999).

Fire Retardation—Green roofs are found to have better fire resistance values compared to conventional roofs (Köhler 2004).

Urban agriculture—With specific design green roofs and walls are suitable for growing fruits, vegetables and herbs.

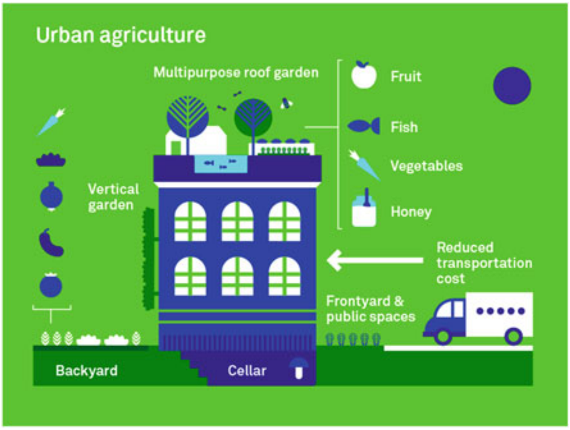
Extended roof life—Green roof systems provide protection to roofing membranes from the effects of UV light, mechanical damage, high thermal temperature fluctuations therefore leading to a longer lifespan.

Reduction of electromagnetic radiation—Green roofs can reduce electromagnetic radiation penetration by 99.4 % (Herman 2003).

6 Urban Agriculture

Urban agriculture is generally the practice of cultivating crops for food in cities. Growing fruits, vegetables and herbs in cities can be combined with other green infrastructure (green roofs and walls) and decentralised water management techniques (RWH) (Fig. 6).

Fig. 6 Blue green urban agriculture



6.1 *What Are the Challenges Regarding Water Conservation?*

Cultivating crops for food often requires significant amount of water for irrigation, which could be an 'extra burden' for water demand in urban areas. Moreover, municipal water supplies are usually more expensive and energy consuming than agricultural water supplies, as municipal water must go through particular treatment to meet drinking water standards (Nolasco 2011). Thus, it is of key importance that water-use efficiency and conservation practices are incorporated into urban agriculture. Such techniques could include rainwater harvesting, grey water harvesting, physical water retention methods, drip irrigation, etc.

Showcase Zuidpark, The largest rooftop garden in Europe

In 2012, the conventional rooftop of Zuidpark, a former administrative building in an industrial zone of Amsterdam, was redeveloped to host a 3,000 m^2 garden, so far the largest in Europe, where organic vegetables, herbs and flowers are cultivated (IGRA 2012). The roof garden substrate was specifically developed to be used for urban agriculture. Unlike common practices of urban agriculture, agricultural products are not for sale but are served to the building's common restaurant. The rooftop farm is a place where people meet, rest, have lunch and can even take gardening lessons. Most of all, Zuidpark's farm roof represents a great example of creative thinking.

Source Helga Fassbinde (http://www.biotope-city.net)

7 Decentralised Systems to Manage and Reuse Storm Water Run-off On-site

7.1 What is Decentralised Storm Water Management?

Storm water management involves practices that improve the quality and reduce the quantity of storm water run-off, in order to prevent or mitigate flooding, waterways contamination and negative-related consequences, such as infrastructure damage, bank alterations and erosion, habitat destruction and quality degradation of streams, rivers and coastal waters.

Traditionally, storm water run-off from streets, roofs, pavements and other impervious surfaces in urban areas is collected through pipes and sewer systems and conveyed quickly offsite, where it is either discarded straight away into a water receiver, or it is first treated by a Wastewater Treatment Plant. Also known as a 'drained city' approach. Currently, urban water management puts emphasis on the decentralised storm water and rainwater management such as Low Impact Development (LID) for USA, Decentralized Urban Design (DUD) for Germany, Water-Sensitive Urban Design (WSUD) of Australia, Sound Water Cycle on National Planning (SWCNP) for Japan and Smart Watergy City (SWC) for South Korea, and have similar concepts with on-site rainwater and storm water management and source control (Table 3).

The MUS alternative, offers a distributed approach involving the implementation of different decentralised on-site storm water management techniques, trying to mimic the natural drainage process. These decentralised systems select the attenuation (temporary storing and release at a later stage), infiltration to the ground, or conveyance (slow transport) of the urban run-off. In addition, they aim at filtering out pollutants and allowing sediment settlement. They integrate the normative

Table 3 Decentralised storm and rainwater management approaches among countries

Classification	Concept	Characteristics
South Korea	Smart Watergy City, U-Eco City (SWC)	Water management based on ubiquitous Construct of ecosystem using green energy and technology Watergy: water, energy and ecology
USA	Low impact development (LID)	Management of pollution sources and rainwater management based on green land Best management practices (BMPs) Water quality capture volume (WQCV) Green infrastructure (GI) Smart water grid
Australia	Water-sensitive urban design (WSUD)	Rainwater management adaptable to climate change Management and using of storm water run-off
Germany	Decentralised urban design (DUD)	Decentralised rainwater management by arcology Management and using of storm water run-off
Japan	Sound water cycle on national planning (SWCNP)	Sound water cycle by rainwater management Reduction of storm water run-off Detention and infiltration in watershed

Source UN ESCAP (2012)

values of environmental protection and restoration, water supply reliability, flood control, public health, amenity and leisure, energy consumption reduction, climate change adaptation and economic viability.

7.2 What Are the Typical Schemes and Techniques?

The decentralised storm water management schemes use a combination of processes, mechanism and components to deliver their expected benefits. The processes involved in these schemes can be broadly classified as source control, swales and conveyance channels, filtration, infiltration, retention and detention, wetlands, inlets/outlets and control structures.[1] The MUS concept incorporates these distributed storm water management techniques with a shift to the green infrastructure approach (US EPA 2008), to be implemented in different scales: site-specific, neighbourhood and regional. Wide-scale design and implementation of combined Green Storm water Infrastructure tools such as rain gardens, infiltration systems, constructed wetlands, vegetated swales, etc. can provide numerous benefits and support a sustainable Blue and Green urban environment (Table 4).

[1] For more information, visit http://www.susdrain.org.

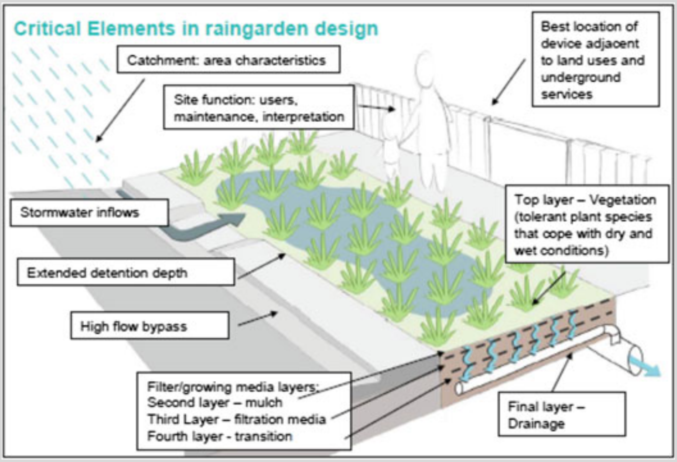
Table 4 Decentralised storm water management techniques

Categories	Techniques/measures
Source control	Green roofs, rainwater harvesting, permeable paving and other permeable surfaces
Swales and conveyance channels	Swales, channels and rills
Filtration	Filter strips, filter trenches, bioretention areas
Infiltration	Soakaways, infiltration trenches, infiltration basins and rain gardens
Retention and detention	Detention basins and retention ponds
Wetlands	Wetlands

Source www.susdrain.org

What Are Rain Gardens?

Rain gardens are shallow-planted depressions designed to receive rainwater from hard surfaces such as roofs, paved areas or roads. The excess run-off infiltrates into the soil, reducing peak flow on site and recharges groundwater. The soil layers underneath also assist in the removal of pollution, such as nitrogen, phosphorus and fertilisers, which are washed off from hard surfaces. The plants in the rain garden help to further filter out pollution. Rain gardens can be applied at a variety of scales and are self-sufficient compared to regular gardens as they use storm water directly, thus resulting in reduced domestic water use for gardening.



Raingarden design principles. *Source* Clear Water (2012a); http://www.clearwater.asn.au/

Opportunities for Retrofitting: Rain gardens can be constructed at a low cost in new or existing sites. They could be easily retrofitted to existing domestic houses, commercial and industrial buildings with downpipes connected to subsurface water drains.

What Is Permeable Paving?

Permeable pavement is a method of paving that allows water to infiltrate into the ground as it falls rather than running off into piped storm water drainage system. Porous pavements are mostly suitable to be implemented on light traffic loads such as streets with low traffic volumes, parking lots, private driveways, pedestrian paths or footpaths, public squares, etc. They are most effective when used in conjunction with other measures such as vegetable swales, cisterns, etc.

Source Water Sensitive Urban Design in Sydney http://www.wsud.org/

Common Types:

- Porous asphalt is the same as regular asphalt except it is manufactured with the fine material omitted, leaving voids that allows water to infiltrate.
- Concrete, ceramic or plastic pavers—Designed to leave gaps between allowing run-off penetration.
- Grid systems or open cell pavers are made from plastic or concrete grid filled with soil or aggregate so that water can percolate through

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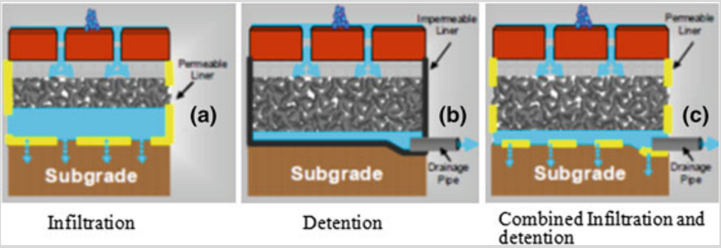
Source University of Maryland Extension (2011)

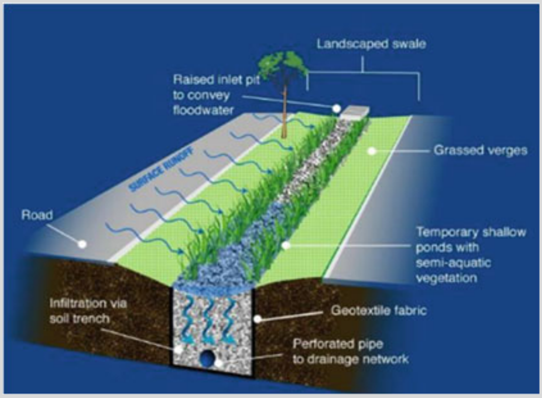
Design Characteristics: There are several options for the design and construction of systems. After infiltrating through the pavement surface, the water can be stored in a sink tank or in plastic cellular systems.



The associated costs for impervious pavements are influenced by the type of material, the preparation of the site, the installation and the maintenance of the system. Installation and maintenance is likely to be more expensive than the construction of conventional impervious surfaces. Typical construction costs vary from $5—10/sq.ft. (Clark et al. 2008a, b).

What Are Swales?

Swales are shallow, broad and vegetated channels filled with porous filter media to provide on-site treatment of storm water run-off. Storm water is directed and collected into the shallow depressed area and slowly filters through the vegetated soil media where pollution is removed through physical and biological processes. Water then passes through a transition layer and finally drains into a drainage layer. Depending on the design, treated storm water is usually collected through a piping system inside the draining layer and led downstream to waterways or storage systems, or can infiltrate through the underlying soils. Swales should also contain an overflow or inlet for flood events. Swales need regular maintenance.



Schematic of a typical bioretention swale (*Source* FAWB, Facility for Advancing Water Biofiltration (2008))

What Are Infiltration Trenches?

An infiltration trench is an excavation filled with permeable material, such as rock and gravel, which is used to capture, treat, store and infiltrate storm water, enhancing the natural capacity of the ground to store and drain. Infiltration trenches allow water to infiltrate into the soil from the bottom and sides of the trench. The treatment procedure involves retention of sediments, nutrients, dissolved heavy metals and other toxic substances. They can be constructed at open spaces, such as parking lots and streets, as a simple trench system or combined with other filtering systems, such as grassed swales and vegetated filter strips to increase pollution removal.

Main limitations regarding this technique concern the high clogging potential, the regular maintenance needed to remove retained pollutants and preserve efficiency and the risk of groundwater contamination if soils are coarse.

Source Melbourne water

http://www.melbournewater.com.au/Planning-and-building/Stormwater-management/

What Are Retention Ponds? Retention ponds can provide both storm water attenuation and treatment, while supporting emergent and submerged aquatic vegetation along their shoreline. Run-off is detained in the pool, while the retention time promotes pollutant removal through sedimentation and biological uptake mechanisms. Maintenance requires removal of debris and litter, cleaning of the inlet, sediment removal and vegetation management.

The need for adequate surface may constrain the construction of retention ponds in highly dense urban areas, while if the inflow is limited (due to the small number of storm events) and combined with poor maintenance anaerobic conditions may occur and consequent health risk.

Source www.susdrain.org

What Is a Constructed Wetland? Constructed wetlands are artificial treatment systems that mimic the physical, chemical and biological functioning of natural wetlands in order to remove pollutants from storm water. The main processes involved are physical detention and filtration of suspended solids and dissolved pollutants as well as biological and chemical uptake by the wetland vegetation. According to US EPA, constructed wetlands are among the most effective measures to remove contaminants from storm water and present high range of applicability, excluding highly urbanised areas and arid climates.

Moreover, they can increase aesthetics and provide habitat to several ecosystems. Careful consideration must be integrated into the design before constructing a wetland to manage significant issues such as the necessity of a large open space, the undesired presence of mosquitos and possible disturbance of the natural environment.

Storm water Wetland in Philadelphia (*Source* http://www.phillywatersheds.org)

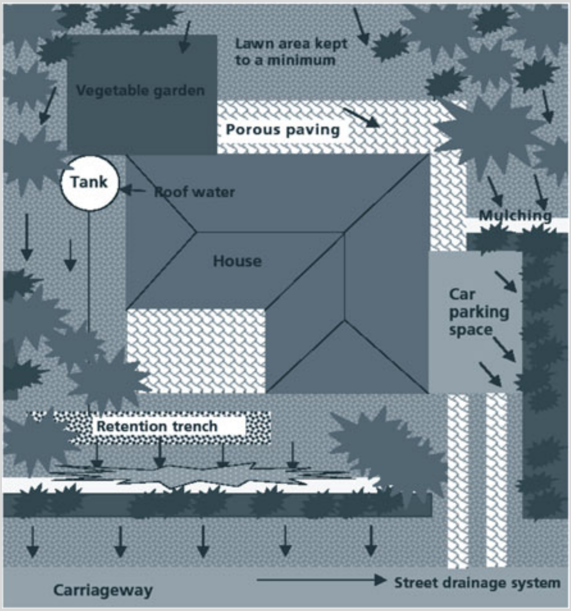
8 Integrating Multiple-Use Perspectives

The integration of multiple-use perspective targets the optimal synergies between the aforementioned interventions and techniques with the purpose of delivering multiple benefits, reproducing the natural pre-development process to the best possible degree and boosting the ecosystem services. For example, combining green roofs with urban agriculture and rainwater harvesting can provide storage and peak flow reduction while increasing food provision, aesthetics and leisure, reducing energy consumption and mitigating the heat island effect. Key to a concrete integration is planning and governance. To achieve the desired results urban planning must endorse the blue-green thinking paradigm, while an appropriate institutional setting must be in place to act as an enabling support environment.

Securing financial resources and providing incentives (including subsidies) are also important factors for the uptake and expansion of these techniques. Design must consider the vertical integration of measures and their horizontal application in all possible scales: single dwellings, residential multi-units, public and commercial buildings, streetscapes, blocks, etc.

Some example applications of combined blue-green interventions are provided below, followed by a summary overview of the benefits (Table 5) and indicative costs (Table 6) of the blue-green techniques described before.

Example 1



Possible overall strategy for a typical suburban home. A rainwater tank supplies rainwater for toilet flushing, washing machine, and for outdoor use whilst water efficient fittings reduce main water consumption elsewhere. During prolonged or heavy rain, water overflows from the rainwater tank to a retention trench. Storm water run-off from paths, driveways and lawns is directed to garden areas. Excess run-off from impervious surfaces is directed to the retention trench, or overflows to the street drainage system.

Source Hobart City Council (2006)

Table 5 Overview of the benefits of the various Multiple-Use perspectives and techniques

Blue and green measures	Water				Natural hazards		Environment			
	Water supply/ reduction of water demand	Reduction of storm water runoff	Restoration of water cycle/ aquifer recharge	Reduction diffuse pollution/ water treatment	Flood risk reduction	Disaster management (e.g. firefighting)	Mitigation of urban heat island effect/ improvement of microclimate	CO_2 reduction/ improved air quality	Reduction of noise	Increased biodiversity
Green roofs	(x)	x	x	x	x		x	x	x	x
Living walls, green facades		x		x			x	x	x	x
Green spaces (gardens, parks, lots, squares, streets, etc.)		x	x	x	x		x	x	x	x
Permeable paving	(x)	x	x	x	x					
Swales/ bioswales		x	x	x	x	(x)		x		x
Filter strips/ trenches		x	(x)	x	x					x
Rain gardens	x	x	x	x	x		x	x		x
Retention/ detention ponds	x	x	x	x	x	x	x	x	x	x
Constructed/ artificial wetlands	x	x	x	x	x	x	x	x	x	x

(continued)

Table 5 (continued)

Blue and green measures	Water				Natural hazards		Environment			
	Water supply/ reduction of water demand	Reduction of storm water runoff	Restoration of water cycle/ aquifer recharge	Reduction diffuse pollution/ water treatment	Flood risk reduction	Disaster management (e.g. firefighting)	Mitigation of urban heat island effect/ improvement of microclimate	CO_2 reduction/ improved air quality	Reduction of noise	Increased biodiversity
Rainwater harvesting	x	x	x	(x)	x	x				
Wastewater reuse and recycling	x	x	(x)	x	x	x		x		
Urban agriculture	(x)	x	x	x	x		x	x		

Blue and green measures	Socio-economic						Well-being			Education, RTD	
	Energy saving	Lowering of water and/or energy bills	Food supply	Self sufficiency	Local job creation	Poverty alleviation	Amenity and aesthetic improvement	Leisure	Health	Education and awareness	Technology development
Green roofs	x	x	(x)		x		x	x	x	x	x
Living walls, green facades	x	x	(x)		x		x		x	x	
Green spaces (gardens, parks, lots, squares, streets, etc.)			X		x	x	x	x	x	x	
Permeable paving					x		x				x
Swales/bioswales					x		x				
Filter strips/ trenches					x		x				

(continued)

Table 5 (continued)

Blue and green measures	Socio-economic						Well-being			Education, RTD	
	Energy saving	Lowering of water and/or energy bills	Food supply	Self sufficiency	Local job creation	Poverty alleviation	Amenity and aesthetic improvement	Leisure	Health	Education and awareness	Technology development
Rain gardens	x	x	X	x	x		x		x	x	
Retention/ detention ponds	x				x		x	x	x	x	
Constructed/ artificial wetlands	x				x	x	x	x	x	x	x
Rainwater harvesting	x	x	(x)	x	x	x	x		x	x	x
Wastewater reuse and recycling	x	x	(x)	x	x	(x)				x	x
Urban agriculture	x		X	x	x	x	x		x	x	

Table 6 Indicative costs of multiple-use perspectives and techniques

BG measures	Installation cost	Maintenance cost
Green roofs	10$/sq. ft. (extensive green roof) and 25$/sq. ft. (Intensive green roof) (US EPA 2014a, b)	0.75–1.50/sq. ft. annually (US EPA 2014a, b)
Living walls	The cost of materials of a living wall ranges from $60 to $90 per sq. ft. However, the overall cost (plants, soil irrigation, installation) of construction could reach double this amount. (Continuing Education Centre 2014) ***Showcase: Large-scale outdoor green wall hydroponic, 2009 The wall is 206 sq. m. with a total cost of $350,000 (158 $/sq. ft.) (***DEPI 2014***)***	Pruning and panels adjustment :14.41€ ($19.81)/m^2/year (Perini and Rosasco 2013) Irrigation: 0.96€ ($1.32)/m^2/year Panels replacement (5 %): 6.05€ ($8.32)/m^2/year Plant species replacement (10 %): 2.75 € ($3.78)/m^2/year Pipes replacement (irrigation system): 2.85€ ($3.92)/m^2/year Total Maintenance cost : 27€ ($37.11)/m^2/year (2.5€ ($3.4)/sq. ft./year))
Permeable paving	1. Porous Concrete: $2.00 to $6.50/sq. ft. 2. Porous Asphalt: $0.50 to $1.00/sq. ft. 3. Interlocking Pavers: $5.00 to $10.00/sq. ft. (University of Maryland Extension 2011)	Annual maintenance costs about 1–2 % of the construction cost (Prince George's County, Maryland 2014)
Swales/ bioswales	Swales: 15–20$/m^2 (Fletcher et al. 2003) Swale bioretention systems: $100–120/linear metre including vegetation (for this system the filter zone has a width of 1 m and the swale has a top width of 3–4 m) (Leinster 2004)	$2.50—Grass swale ($/m^2/yr) $9.00 Vegetated swales ($/m^2/yr) (initial) $1.50 Vegetated swales ($/m^2/yr) (after 5 yrs) (Lloyd et al. 2002)
Buffer/filter strips	$10–$15/sq. meter—Sydney Grass buffer strip $20–$50/sq. meter—Native grasses and shrubs (URS 2003)	Typical maintenance costs are about $350/acre/year (US EPA 2014b)
Rain gardens	Cost will vary depending on the garden's size and the types of vegetation used; however, professional installation of a rain garden typically costs $10–$12/sq. ft. (Charles River Watershed Association 2008)	The Typical Annual Maintenance cost is estimated as 5–7 % of the construction cost. Maintenance costs are likely to be higher in the first few years due to the intensive effort needed to establish the system (Environmental Protection Agency, Victoria 2008)
Retention/ detention ponds	Typical construction costs in 2004 dollars range from approximately $25,000 to $50,000 per acre-foot of storage. (Pennsylvania Department of Environmental Protection 2006)	Annual cost of maintenance (especially sediment and vegetation removal) estimated at 3–5 % of construction costs (Pennsylvania Department of Environmental Protection 2006)

(continued)

Table 6 (continued)

BG measures	Installation cost	Maintenance cost
Constructed/ artificial wetlands	Small-scale wetland with an inlet pond, macrophyte zone, bypass weir and channel: \$90–\$100/m^2. Larger-scale wetland to treat recirculated lake water: \$65/m^2 (Leinster 2004)	Wetlands typically cost 2–6 % of the construction cost to maintain each year. Smaller wetlands are cheaper to maintain (Environmental Protection Agency, Victoria 2008)
Rainwater harvesting	The capital cost of an RWH system can range from \$1.50 to \$3.00 per gallon of storage (for simple systems) to \$3.5–\$8 per gallon for more sophisticated systems (US EPA 2013)	Total Annual cost of primary routine maintenance and corrective activities associated with cisterns was estimated at around \$1000 (WERF 2009; US EPA 2013)
Urban green spaces	A study on the cost-benefit performance of street and park trees in five US cities from different States (McPherson et al. 2005) estimated total annual municipal expenditures for tree planting and ongoing maintenance to range from \$15 to \$65 per tree (McPherson et al. 2005)	

Example 2

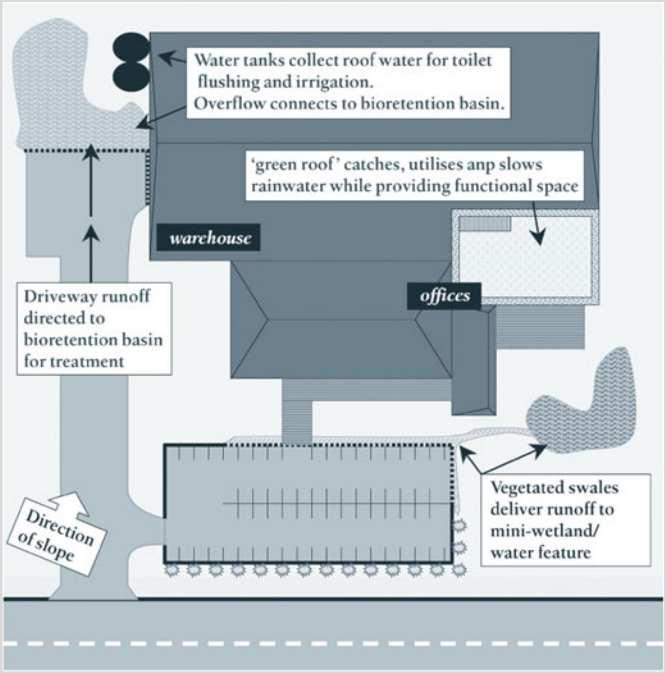


Diagram of a possible industrial site layout incorporating a mini-wetland landscape feature, green roof, vegetated swales delivering car park run-off to the mini-wetland, rainwater harvesting for non-potable uses and a bioretention rain garden to collect driveway run-off and water tank overflow.

Source Hobart City Council (2006)

Example 3

Royal Park Storm water Harvesting Project—City of Melbourne Royal Park, Melbourne, Victoria

The Trin Warren Tam-borne urban wetland (also known as the Royal Park Wetlands) was constructed to treat storm water and run-off from the roads, to provide a habitat for wildlife as well as for supplying treated water to the residents of Melbourne. The wetland was engineered to have two linked ponds into which storm water is diverted to be treated by native Australian plants and other biological processes.

The treated water was then diverted into a storage wetland passing through an ultraviolet disinfection system in order to be utilised for city purpose irrigation. The construction also contains a 6-million-litre groundwater storage facility with two distribution tanks. The wetland has provided home for more than 270 species of birds and the White's Shink lizard.

Source Clear Water (2012b).

9 The MUS Approach in a Rural Context

In many areas around the world where centralised water services are absent, populations living in poverty have limited or no access to clean water for the satisfaction of various needs, ranging from domestic uses, such as drinking, cooking, hygiene and sanitation, to productive activities (e.g. irrigation, livestock production and small-scale enterprises such as brick making and food processing). Existing applications in low-income countries rely on the single-use approach where planning, investment and management of water services targets a single use such as drinking or irrigation with possible negative impacts in human health and sustainability as in the end people use the supplied water for multiple purposes (Renwick et al. 2007).

9.1 What Is the MUS Approach?

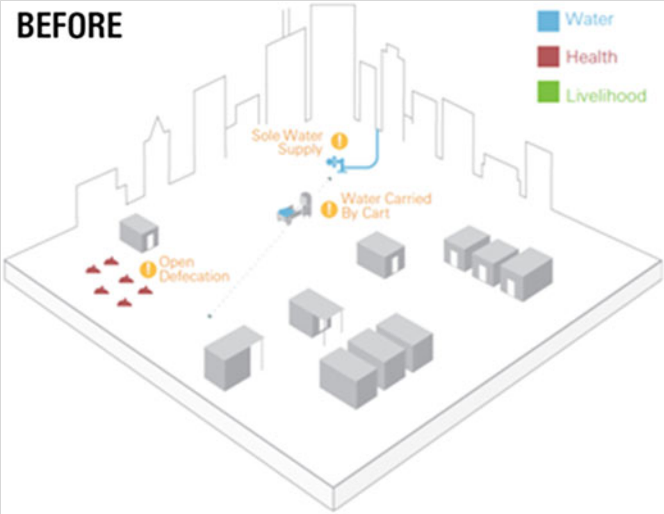
Multiple-Use Water Services or MUS is an integrated and participatory approach in water services that considers (poor) consumers' actual water needs as a starting point in order to design, finance and manage existing or new water infrastructure for multiple domestic and productive purposes (Van Koppen et al. 2006; Renwick et al. 2007).

9.2 Why Apply MUS?

MUS is a relatively new approach, which has received a great deal of acceptance among policymakers, programme managers, investing organisations, water professionals and academic institutions (Adank et al. 2012). Multiple use water services can be more expensive compared to single-use services but have the potential to provide a wide range of economic and social benefits to consumers (Renwick et al. 2007):

- Increased income and multiple social benefits (improved human health, more and safe food, time savings, social equity) for more people;
- Vulnerability and poverty reduction;
- Improved sustainability of service delivery as MUS effectively target users' needs and priorities and result in increased income, encouraging communities to operate, sustain and finance services better.

Example: Multiple Sources for Multiple Water Uses in Urban Areas (WI 2012)



A single tap provides drinking water to consumers.

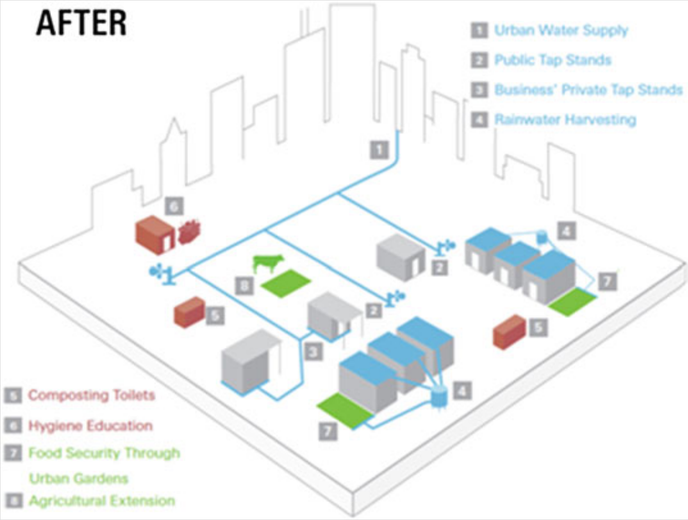
Water transport is distant leading to higher cost of water and often long waiting time.

Phenomena of diarrhoea are usual because of open defecation and limited hygiene.

Enterprises use less water due to high cost.

The installation of more public tap stands close to households increases available water and reduces wait time and cost for water transport.

With increased available water in addition to hygiene education and composting toilet application, health improves.



Businesses can also benefit from more, closer and cheaper water.

Rainwater harvesting schemes can provide water for household needs and commercial gardens.

Commercial gardening boosts income generation, reinforcing water infrastructure sustainability.

10 How Can We Calculate the Value of MUS Systems?

10.1 An Ecosystem Services Approach

Ecosystem Services (ESS) are the conditions and processes through which natural ecosystems and the species that make them up sustain and fulfil human life. Ecosystem services are also defined as all benefits people receive from ecosystems and can be used to describe connections between nature and human welfare (MA 2005). Ecosystem services changes result in outcomes, benefits or harms that people value, introducing the need of valuation and quantification of social welfare. Ecosystems and their functions and processes provide outputs of goods and services, which generate benefits to human populations that can then be measured as increases in human well-being (EFTEC 2005; Fig. 7).

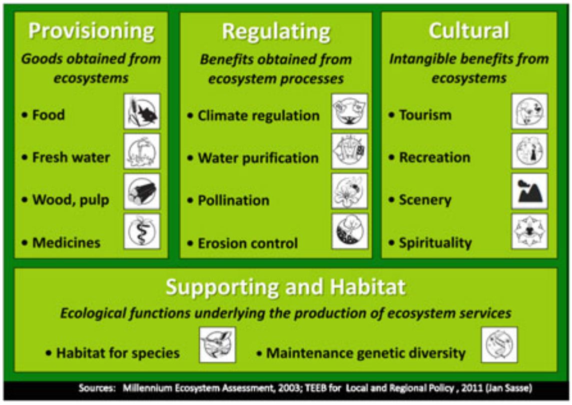


Fig. 7 Classification of ecosystem services (*Source* TEEB (2010c))

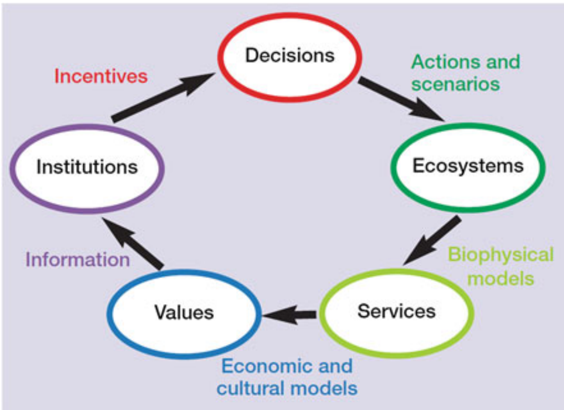


Fig. 8 Integration of ecosystem services into decision-making (*Source* Daily et al. (2009))

10.2 An Ecosystem Approach for Decision-Making

An ecosystems approach provides a framework for looking at whole ecosystems in decision-making and valuing the ecosystem services they provide, to ensure that society can maintain a healthy, resilient, natural environment now and in the future (Department for Environment 2013). The framework links the social, environmental and economic impact of an activity and evaluates it accordingly. It is a holistic approach that looks and quantifies not only costs but also benefits ranging from aesthetical pleasure and species preservation to job creation and property value. Carrying out economic valuation of the ecosystem services involved will help you to incorporate the value of the natural environment in your decision (Fig. 8).

The Challenge

Ascribing values to ecosystem services is not an end in itself, but rather one small step in the much larger and dynamic arena of political decision-making. Our challenge today is to build on this foundation and integrate ecosystem services into everyday decisions. This requires a new focus on services beyond provisioning services; an understanding of the interlinked production of services; a grasp of the decision-making processes of individual stakeholders; integration of research into institutional design and policy implementation; and the introduction of experimentally-based policy interventions designed for performance evaluation and improvement over time (Daily et al. 2009).

10.3 Economic Valuation of Ecosystem Services

Economic valuation is broadly accepted as an approach that can effectively link ecology and economics to evaluate benefits of management options. It can capture a broad array of environmental values, attributing not only a commercial value (e.g. the monetary value of timber) to an ecosystem service (NRC 2004), but also including many components that have no commercial or market basis (e.g. the aesthetic value of a natural landscape).

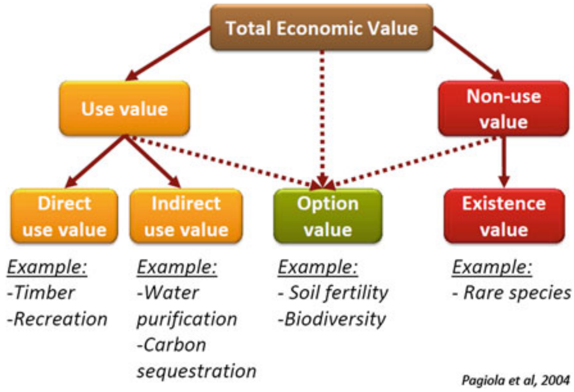
Given that, most ecosystem services are not sold in market, economic valuation techniques can be used to attach an appropriate value to their resulting benefits. Thus, economic valuation provides a systematic way in which environmental values can be factored into choices for better environmental decision-making. Other frameworks to valuate ESS are based on ecological or socio-cultural approaches. By 'values', we mean an attribute of a service or good, while valuation is the process of quantifying this attribute. The term 'economic value' describes the change in human wellbeing—welfare generated by a product.

10.4 How to Value Ecosystem Services?

To increase their total well-being people express preferences stemming from both use and non-use values. The sum total of use and non-use values related to a resource or an aspect of the environment is called Total Economic Value (TEV) and offers a useful framework to value ecosystem services. The metric for quantifying economic values is usually money (Fig. 9).

Use values encompass **direct use** values; consumptive (e.g. value of timber, fish etc.) or non-consumptive (e.g. recreation, aesthetics) and **indirect use** values that

Fig. 9 Components of total economic value



relate to the services provided by nature (e.g. air and water purification, erosion prevention) (de Groot et al. 2010). **Non-use values** is the importance attributed to an aspect of the environment in addition to or irrespective of its use values and could be described as the value attributed to its simple existence. **Option value** is when an individual derives benefit from ensuring that ecosystem services will be available for use in the future (EFTEC 2005).

Economic Valuation Techniques (de Groot et al. 2010)

A number of ways exist to translate economic and some socio-cultural values of ESS into monetary values. Market prices (marginal values) exist for many ecosystem services, especially the provisioning services such as timber and non-timber forest products. Values of other services are often also expressed through the market but in an indirect way, e.g. through (avoided) damage cost methods (for regulating services), hedonic pricing (influence of environmental attributes on property value) or travel cost methods for some cultural services such as aesthetically pleasing landscapes. Other alternatives are contingent valuation (e.g. questionnaires measuring preferences) and benefit transfer (i.e. using data from comparable studies).

TEV is a useful approach even if we cannot determine monetary values for all benefits. Having a monetary value for some benefit categories may be enough justification for choosing a conservation option over a more resource-exploitative alternative. In most cases, a partial monetization is more likely, more feasible and quite possibly less risky. By less risky, we mean that any analysis must be credible if stakeholders are to accept its findings (TEEB 2010a; Fig. 10).

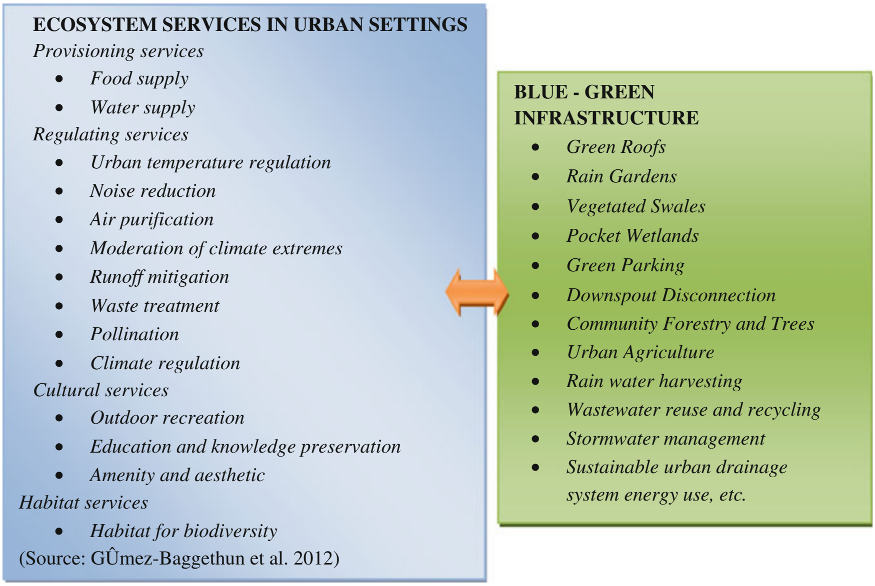


Fig. 10 Interactions between ecosystem services and blue-green infrastructure

Implement the Approach Step by Step (TEEB 2010b)

1. *Specify and agree on the problem*
   This is often a worthwhile effort because views can differ substantially. If key stakeholders share a common understanding of the problem, serious misunderstandings during the decision-making process and implementation can be avoided.
2. *Identify which ecosystem services are relevant*
   Ecosystem services are often interconnected. Identifying which ones are most important to your problem focuses the analysis. Going one by one through the list of services is a simple approach.
3. *Define the information needs and select appropriate methods*
   The better you can define your information needs beforehand, the easier it is to select the right analytical method and interpret the findings. Assessments differ in terms of which services are considered, the depth of detail required, timelines, spatial scope and monetization of the results and other factors. The study design determines what kind of information you get.
4. *Assess expected changes in availability and distribution of ecosystem services*
   If possible, use experts. Also, draw on fieldwork and documented experience from analyses in comparable settings. Use common sense and consult with colleagues on possible changes and their consequences, starting with the most obvious ecosystem services.
5. *Identify and appraise policy options*
   Based on the analysis of expected changes in ecosystem services, identify potential responses. Appraise these in terms of their legal and political feasibility

as well as their potential in reaching the targeted quality, quantity and combination of ecosystem services produced by your → *natural capital*.

6. *Assess distributional impacts of policy options*
   Changes in availability or distribution of ecosystem services affect people differently. This should be considered in social impact assessment, either as part of the analysis or as part of appraising policy options.
   Look out: The relative importance of each step is determined by your situation and objectives. Taken together, adapted to your needs, and incorporated into existing decision-making procedures, they offer guidance for considering natural capital in local policy. Other technical, legal, economic and social information also needs to be considered. The steps can also help you design a monitoring system and thereby track the condition of your natural capital.

10.5 How Can Economic Valuation Assist Policymaking?

- Providing information about benefits (in monetary terms or otherwise) and costs;
- Creating a common language for policymakers, business and society allowing the real value of ecosystems services to become visible and be accounted in decision making;
- Revealing the opportunities to work with nature by demonstrating where it offers a cost effective means of providing valuable services (e.g. water supply or reduced flood risk);
- Emphasising the urgency of action through demonstrating where and when the prevention of biodiversity loss is cheaper than restoration or replacement;
- Generating information about value for designing policy incentives (to reward the provision of ecosystem services and activities beneficial to the environment, to create markets or level the playing field in existing markets, and to ensure that polluters and resource users pay for their environmental impacts). (*Source* TEEB (2010c))

The Project (TEEB 2010b)

A change in national legislation has increased treatment requirements by lowering acceptable bacterial levels. The added designation of new residential areas will also increase volume to a level that can no longer be handled by your city's plant

Step 1 As director of the responsible department, you commission a pre-feasibility study for the construction of a modern plant that meets both quality and quantity requirements. The province-level development bank has an attractive credit scheme to help finance converting an agricultural site, but the costs are high and would require a considerable portion of the city's infrastructure budget. The city council agrees that an alternative solution is needed.

Step 2 At a workshop, you learn about the utility of wetlands for wastewater treatment. This helpful coincidence makes you realise what a preliminary ecosystem services appraisal would have shown: There is a wetland in your city close to an abandoned railroad track, which is neither accessible nor attractive.

Step 3 You invite the workshop expert who tells you that the location and condition of your wetland are suitable. He recommends you to determine how much rainwater run-off can be redirected to the wetland for rehabilitation, to examine flood control needs for neighbouring settlements and to establish whether redirected waters will reduce the volume flowing to the old plant.

Step 4 A team of colleagues consults available data for assessing the ecosystem services involved.

Step 5 Subsequent calculations reveal that this plan is considerably less costly than constructing a new treatment plant.

Step 6 It has the added benefit of liberating funds for other infrastructure projects and will not increase citizens' water bills. The area is uninhabited and unused, so an impact analysis on current users is unnecessary.

A local NGO agrees to help plant the reconstructed wetland and you convince the earthworks company to remove the railroad tracks to make space for a cycling and walking path.

Conclusions

The need to replace or construct new infrastructure presents an opportunity to examine ways to invest in more green, instead of grey, infrastructure or at least redesign projects in order to minimise damages to ecosystem services and biodiversity. There are many such opportunities in water provisioning (catchment management instead of water treatment plants), flood regulation (flood plains or mangroves rather than dykes) and landslide prevention (maintaining slopes covered with vegetation). Green infrastructure usually provides additional ecosystem services such as recreational value (habitat service)

11 Tools for Supporting Multiple-Use Water Services

MUS interventions provide an integrated urban water and urban green design, operation and management approach for sustainable cities. This more holistic approach would present a win-win scenario, in which urban green would be utilised as infrastructure for water services (e.g. mitigating urban floods) while urban water infrastructure would be used as irrigation source for urban green, increasing their performance in a range of services including amenities, reducing heat island effect and increasing ecosystem services. The urban water cycle is a complex system driven by time varying and stochastic inputs (rainfall, water demand). Thus, specialised models are required to support the optimal design, operation and management of urban water networks.

One of the most prominent urban water modelling tools that employs to some extent combined modelling of blue and green assets is **UVQ** (Mitchell and Diaper 2010). UVQ runs with daily time step to estimate the amount of water required for irrigating green areas and can estimate the reduction of potable water required for irrigation in case treated wastewater and/or harvested rainwater are used supplementary to potable.

Another model that can be used to study some urban water flows involved in MUS concept is **Aquacycle**, a daily urban water balance model developed to simulate the total urban water cycle as an integrated whole and investigate the potential use of locally-generated storm water and wastewater as a substitute for imported water. It can model from a single land block, such as a residential property, to an entire urban catchment (Mitchell 2005).

Music (Model for Urban Storm water Improvement Conceptualisation) is another MUS-related tool, specialised in helping urban storm water professionals visualise and compare possible strategies to tackle urban storm water hydrology and pollution impacts. Music allows the comparison of storm water management measures in order to achieve the best water quality, hydrology and cost outcomes. Music incorporates the recent findings of the Facility for Advancing Water Biofiltration (FAWB) to provide more accurate prediction of filtration-based treatment measures, especially bioretention and infiltration systems (MUSIC 2013).

The EPA **SWMM** is a storm water management model used for studying single events or continuous simulation of run-off quantity and quality from urban areas. The run-off component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate run-off and pollutant loads. The routing portion of SWMM transports this run-off through a system of pipes, channels, storage/treatment devices, pumps and regulators. SWMM tracks the quantity and quality of run-off generated within each subcatchment, and the flow rate, flow depth and quality of water in each pipe and channel during a simulation period comprised of multiple time steps (Rossman 2010).

WASP is a decision-supporting tool for developing policies and management protocols for sustainable irrigation of urban landscapes such as parks, sporting ovals, golf courses, etc. The name WASP comes from the acronym for Water-

Atmosphere□Soil□Plant. WASP is designed to estimate monthly values of required irrigation specific to the environment (soil, macro□climate & micro□climate characteristics), composition (planting characteristics) and function of the urban landscape (type of landscape outcome such as premium lush, moderate green or low maintenance), corresponding to different climatic years such as wet, dry and average years (IF Technologies 2013).

The previous models are versatile and very efficient for the type of applications they are intended for. However, these models do not offer the holistic approach required to explore the vision of blue-green services fully. For example, from all previous models, only UVQ can estimate both the irrigation needs and the portion of this demand that can be covered by storm water. However, UVQ does not offer a fine time step (time step fixed to 1 day) to simulate the peaks of run-off discharge. Furthermore, none of these models provides a metric to quantify the mitigation of the urban heat island effect.

UWOT is a bottom-up (micro-component based) urban water cycle model, which simulates demand at multiple time steps starting at the water appliance level. Most urban water models use a hydraulics-based conceptualisation of the urban water network, simulating actual water flows, including run-off, potable water and wastewater. UWOT uses an alternative approach based on the generation, aggregation and transmission of a demand signal, starting from the household water appliances and moving towards the source. The simulation results in the estimation of: (i) potable water demand, (ii) water level changes inside the tank and reservoirs, (iii) leakages, (iv) evaporation, (v) run-off, (vi) energy consumption (including both energy required for water circulation (e.g. pump of rainwater inside tank) and energy consumed by the water appliances (e.g. heat water for showering) and (vii) capital and operational costs. More details on UWOT can be found in the publications of Makropoulos et al. (2008), Rozos and Makropoulos (2012, 2013) and Rozos et al. (2013).

UWOT can be used in a wide range of urban water cycle applications representing any type of urban water network. Like any specialised model, a certain level of expertise is required to prepare a new UWOT project. To help beginners set up a new project, a simplified GUI was prepared serving as a front end to the UWOT engine, which runs seamlessly a set of predefined urban water networks (four predefined networks at household level and two at development level). An example of these predefined UWOT networks are shown in Fig. 11. This custom UWOT is called **MUS-Designer**.

MUS-Designer can simulate MUS technologies both at household and at development level. At household level, MUS-Designer simulates the potable water demand, the evaporative cooling (i.e. the energy absorbed from the environment during evapotranspiration) and the electric energy consumption of water appliances. The household water network can be conventional or include Best Available Technologies Not Entailing Excessive Costs (BATNEEC) and/or rainwater recycling and/or grey water recycling. The recycled water is used for toilet flushing and washing machines as well as for garden and green roof irrigation (Fig. 12).

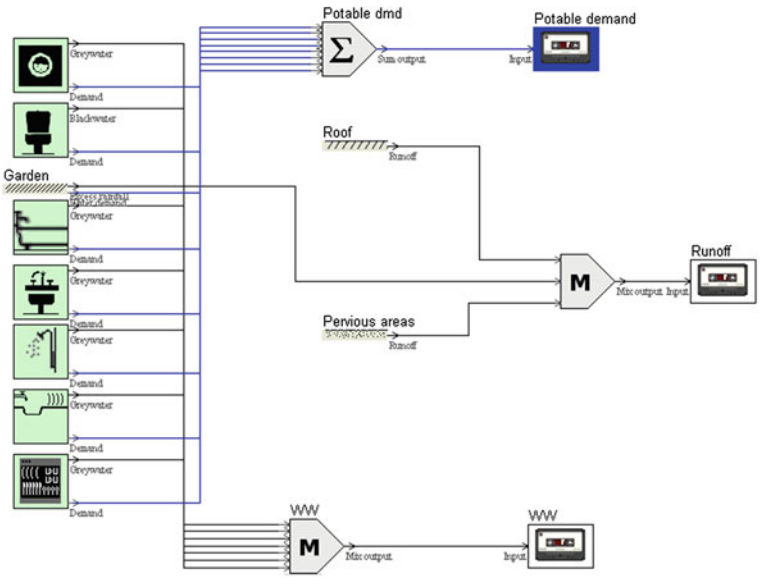


Fig. 11 Water network representation in UWOT of a conventional household

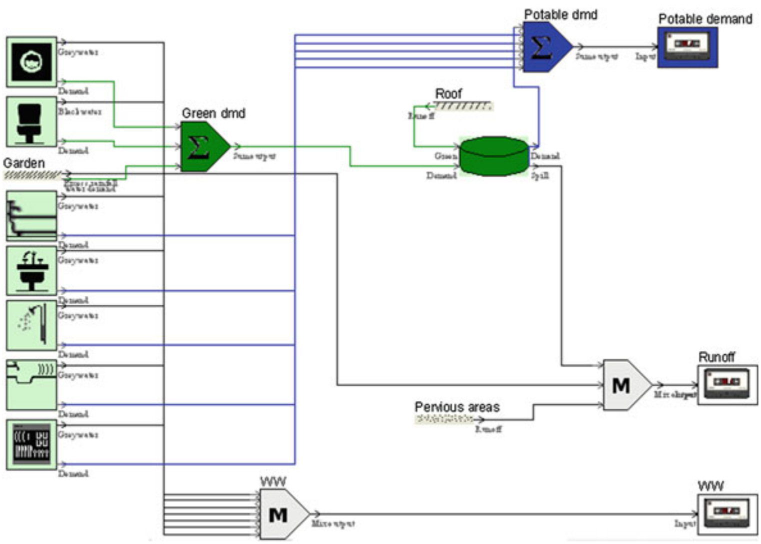


Fig. 12 Water network in UWOT of a household implementing rainwater recycling

At development level, MUS-Designer simulates the potable water demand, the water storage inside service reservoir (used for design purposes to estimate the required average annual inflow and reservoir capacity), the run-off from the development, the evaporative cooling and the solar energy on the development surface. The last two can be used to derive a metric regarding the heat island reduction benefit that green areas offer to urban environment.

The MUS-Designer, via a user-friendly interface, simulates the urban water cycle fluxes related to both blue services (potable demand, run-off volume) and green services (irrigation needs, run-off volume). Then, provides metrics related to the performance of these two services and to the benefits derived from their integrated operation (reduction of required raw water inflow, run-off mitigation and reduction of heat island effect).

Keywords and Definitions

ESS	Ecosystem Services
Green roof	Roof of a building that is entirely or to an extent covered with vegetation planted over a waterproofing membrane
Green walls	Vertical plants either grown on freestanding structures or attached to interior or exterior walls
Infiltration trench	Excavation filled with permeable material, such as rock and gravel, which is used to capture, treat, store and infiltrate storm water, enhancing the natural capacity of the ground to store and drain
MUS	Multiple use water services
MUSIC	Model for urban storm water improvement conceptualisation
Permeable pavement	Method of paving that allows water to infiltrate into the ground as it falls rather than running off into piped storm water drainage system
Rain gardens	Shallow planted depressions designed to receive rainwater from hard surfaces such as roofs, paved areas or roads
Retention ponds	Provide both storm water attenuation and treatment, while supporting emergent and submerged aquatic vegetation along their shoreline
Swales	Shallow, broad and vegetated channels filled with porous filter media to provide on-site treatment of storm water run-off
SWMM	Storm water management model
Urban agriculture	Practice of cultivating crops for food in cities
Urban water management	Emphasises decentralised storm water and rainwater management, such as Low Impact Development (LID) for USA, Decentralized Urban Design (DUD) for Germany, Water

	Sensitive Urban Design (WSUD) of Australia, Sound Water Cycle on National Planning (SWCNP) for Japan and Smart Watergy City (SWC) for South Korea
UWOT	Bottom up (micro-component based) urban water cycle model that uses an alternative approach based on the generation, aggregation and transmission of a demand signal, starting from the household water appliances and moving towards the source
WASP	Water-atmosphere-soil-plant

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