018530 - SWITCH WP2.1

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

Deliverable 2.1.2. A design manual incorporating best practice guidelines for stormwater management options and treatment under extreme conditions
Part B: The potential of BMPs to integrate with existing infrastructure (i.e. retro-fit/hybrid systems) and to contribute to other sectors of the urban water cycle

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SWITCH Deliverable Briefing Note

SWITCH Document: Deliverable 2.1.2b. A design manual incorporating best practice guidelines for stormwater management options and treatment under extreme conditions **Part B: Review of BMPs in relation to their potential to integrate with existing infrastructure (i.e. retrofit/hybrid systems)**
Deliverable reference: Deliverable 2.1.2 b
Author(s) and Institution(s): **B.SHUTES; Urban Pollution Research Centre, Middlesex University, UK.**
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Audience: All stakeholders involved in planning sustainable urban drainage and stormwater management in future urban environments.
Purpose: This deliverable provides an overview of the current state-of-knowledge in relation to the use of retrofit/hybrid systems and includes a range of examples of these systems.
Background: The SWITCH project sets out to identify, develop, apply and demonstrate a range of scientific approaches and solutions which will contribute to effective and sustainable urban water management. Stormwater management needs to identify source control and sustainable drainage systems that are appropriate for the collection of urban surface runoff and can be adapted or retrofitted from existing conventional drainage systems. The initial section of the review describes the suitability of different Best Management Practices (BMPs) or Sustainable Urban Drainage Systems (SUDS) for retrofitting urban drainage systems, the criteria for their selection including land-take and capital cost, and their maintenance requirements. The advantages and disadvantages of each BMP/SUDS type are listed and the runoff rates and volumes are either reduced or significantly reduced by the majority of BMP/SUDS systems. The next section describes a decision support framework that identifies BMP/SUDS options and provides hydraulically effective solutions that are cost-effective to implement. An Adaptive Decision Support System (ADSS) for stormwater pollution control that incorporates a multi-criteria decision making system for the selection of Best Management Practices (BMPs) is also described. This approach considers the influence of technical, economic, ecological, social and environmental factors. The third section identifies exam the issues concerning whether to retrofit subsurface flow stormwater treatment constructed wetlands into existing urban balancing ponds. Both this and the final section provide examples of retrofitted stormwater wetlands and drainage systems in cities and regions.

Potential impact: The review will potentially have an impact on authorities that wish to introduce sustainable urban drainage systems and assess the feasibility of retrofitting existing systems.
Recommendations: The dissemination of the review should be linked to the environmental and long-term economic benefits of adapting existing drainage systems to environmentally sustainable design criteria.

EXECUTIVE SUMMARY

This document represents the second part of the deliverable for Task 4 (also identified as Task 2.1.2) of the SWITCH project and is therefore identified as Part B of Deliverable 2.1.2. It complements Part A, which reviews and compares the design guidelines which have been established for stormwater management within a range of SWITCH and non-SWITCH countries. Part B is concerned with the incorporation of BMPs/SUDS into the urban drainage environment and is divided into two sections dealing with the potential to integrate BMPs into the existing infrastructure (i.e. retro-fit/hybrid systems) (Part I) and with the ability of BMPs/SUDS to contribute to other sectors of the urban water cycle (Part II).

In Section I, the advantages and disadvantages of BMPs/SUDS with regard to retrofitting to urban drainage systems are assessed based on criteria which include land-take, capital cost, and maintenance requirements. Clogging can be a problem, particularly in the presence of high sediment loads, and to avoid high maintenance demands, pre-treatment by open surface systems such as filter strips and swales is recommended. A decision support framework is described which aims to identify BMP/SUDS retrofit options and provide hydraulically effective solutions that are cost-effective to implement. Flowcharts using four hierarchies direct the user to consider institutional roofs before residential roofs, source controls before off-site controls, and infiltration systems in preference to storage based systems. An Adaptive Decision Support System (ADSS) for stormwater pollution control incorporating a multi-criteria decision making system for the selection of BMPs/SUDS is also presented. This approach considers the influence of technical, economic, ecological, social and environmental factors. In addition, two multi-criteria techniques are discussed, Multi Criteria Comparator (MCC) and Matrix of Alternatives (MoA), together with the results of consulting stakeholders regarding the use of these approaches. Finally, several examples of retrofitted stormwater wetlands are described together with a range of examples of retrofit drainage systems in cities.

In Section II, the range of existing and potential roles of BMPs/SUDS in the urban water cycle in different countries are discussed, including their current and potential roles for drinking water supply, irrigation, wastewater treatment, landscape and biodiversity enhancement, social and amenity purpose, and environmental education. Specific examples include rainwater harvesting using water butts and jars, above ground and underground storage tanks and cellars. On a larger scale, the latest greywater and rainwater water reuse technologies and systems for the irrigation of grass and green space are described. The versatility of constructed wetlands with respect to the treatment of separate and combined sewage and mine drainage identifies the need to select an appropriate type of wetland to match both the water quality and quantity objectives of the treatment. The variations in physical scale with which BMPs/SUDS can enhance the landscape and biodiversity of urban highway and urban green space environments are illustrated by referring to both compact or pocket wetlands and large constructed wetlands. This approach can be extended to brownfield urban regeneration areas and for all these types of projects, the contributions and benefits which can be derived through environmental interpretation and education are stressed.

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I. Review of BMPs in relation to their potential to integrate with existing infrastructure (i.e. retro-fit/hybrid systems)

I.1. Introduction

The suitability of different BMP/SUDS types for retrofitting to urban drainage systems is shown in Table 1, collated from the Construction Industry Research and Information Association (CIRIA) SUDS manual (Woods Ballard *et al*., 2007). Twelve of the fifteen systems listed are considered to be suitable for retrofitting. The criteria for their selection include land-take which especially influences the selection of ponds and stormwater wetlands (Figure 1a) as both have high land-take. Capital cost is also a key factor in the selection of SUDS types with ten being classified as low or potentially low in capital cost. The maintenance requirements are only considered to be high for sand filters, with 14 types respectively requiring low or medium maintenance.

One advantage and one disadvantage of each SUDS type is shown in Table 2 which is also collated from the CIRIA SUDS manual (Woods Ballard *et al*., 2007a). Runoff rates and volumes are either reduced or significantly reduced by the majority of the systems. A disadvantage of several of the SUDS types is clogging by high sediment loads, which has implications for the frequency and cost of their maintenance. The clogging problem highlights the importance of pre-treatment by open surface systems such as filter strips and swales, where blockages are visible and there is easy access for sediment removal. As Table 2 indicates, infiltration basins can potentially fail without appropriate pre-treatment. SUDS types are unlikely to be selected as stand-alone systems and their suitability and role in a treatment train is shown in Table 3. Ten of the listed SUDS types are suitable for source control, of which two, infiltration trenches (Figure 1b) and swales (Figure 1c) are also suitable for the conveyance of drainage. The majority of SUDS types are suitable for site drainage with the exception of pre-treatment types on buildings (green roofs, water butts and rainwater harvesting systems). Only five types are suitable for use in regional drainage systems including detention basins, ponds and stormwater constructed wetlands (Figure 1a) on account of their storage volumes. Construction issues for each BMP/SUDS system are listed in Table 4. It is important to avoid compaction of the soil in the construction of filter strips, bioretention systems, swales and pervious pavements. The implementation of design levels is important for swales, sand filters and infiltration basins.

Table 1: Criteria for selecting SUDS types for retrofitting

SUDS type	Retrofit	Land- take	Capital cost	Maintenance
Green roofs	Yes	None	Low/High	Med
Soakaways	Yes	Low	Low	Low
Water butts	Yes	None	Low	Low
Rainwater harvesting	Yes	None	High	Med
Filter strips	Yes	High	Low	Low
Infiltration trenches	Yes	Low	Low/Med	Med
Swales	Yes	High	Low	Med
Bioretention	Yes	High	Low	Med
Pervious pavements	Yes	Low	Med	Low
Geocellular systems	Yes	Low	Low	Low
Sand filters	Yes	Low	High	High
Infiltration basins	No	High	Low	Low
Detention basins	Yes	Medium	Low	Low
Ponds	Unlikely	High	Med/High	Med
Stormwater wetlands	Unlikely	High	High	Med/Low

(Collated from Woods Ballard *et al*., 2007a)

Table 2: Advantages and disadvantages of SUDS types

SUDS type	Advantage	Disadvantage
Green roofs	Use in high density developments	Maintenance of roof vegetation
Soakaways	Groundwater recharge	Not for poor drainage soils
Water butts	Easy to construct, install and operate	Limited water quality benefits
Rainwater harvesting	Reduce demand on mains water	Potential risk to public health
Filter strips	Effective pre-treatment option	Large land-take required
Infiltration trenches	Can significantly reduce runoff rates and volumes	High clogging potential without effective pre-treatment
Swales	Reduce runoff rates and volumes	Risks of blockage in connecting pipe work
Bioretention	Reduce runoff rates and volumes	Clogging if poor maintenance of surrounding landscape
Pervious pavements	Significantly reduces runoff rates and volumes	Not with high sediment loads
Geocellular systems	High storage volume capacity (up to 90% void ratios)	No water quality treatment
Sand filters	Flexibility of design	Not with high sediment loads
Infiltration basins	Reduce runoff volumes	Potential failure if no appropriate pre-treatment
Detention basins	Cater for wide range of rainfall events	Little reduction in rainfall volumes
Ponds	Cater for all storms	Little or no reduction in runoff volume
Stormwater wetlands	Good removal capability of urban pollutants	Large land-take required

(Collated from Woods Ballard *et al.,* 2007a)

Table 3: Treatment Train suitability of SUDS types

SUDS type	Source control	Conveyance	Site system	Regional System
Green roofs	Yes	No	No	No
Soakaways	Yes	No	Yes	No
Water butts	Yes	No	No	No
Rainwater harvesting	Yes	No	No	No
Filter strips	Yes	No	Yes	No
Infiltration trenches	Yes	Yes	No	No
Swales	Yes	Yes	Yes	No
Bioretention	Yes	No	Yes	No
Pervious pavements	Yes	No	Yes	No
Geocellular systems	Yes	Possible	Yes	Yes
Sand filters	No	No	Yes	Yes
Infiltration basins	No	No	Yes	No
Detention basins	No	No	Yes	Yes
Ponds	No	No	Yes	Yes
Stormwater wetlands	No	No	Yes	Yes

(Collated from Woods Ballard *et al*., 2007a)

(a) Constructed wetland

(b) Infiltration trench

(c) Swale

Figures 1a-c: Examples of BMPs/SUDS

Table 4: SUDS construction issues

SUDS type	Construction issues
Green roofs	Apply waterproof membrane correctly
Soakaways	Manually remove 'smearing' of soil surface
Water butts	Avoid overfilling by ensuring flow diversion
Rainwater harvesting	Avoid cross-connections and mark pipes
Filter strips	Avoid compaction of soil and provide an even slope
Infiltration trenches	Avoid disturbing adjacent soil during construction
Swales	Construct design levels and slopes accurately. Avoid compaction of soil
Bioretention	Test imported soil for pH, organic matter etc. Avoid compaction of soil
Pervious pavements	Prevent soil and mud from entering pavement surface. Avoid compaction of soil.
Geocellular systems	Seek guidance from manufacturer on system-specific best practice
Sand filters	Ensure that surface is completely level
Infiltration basins	Grade base evenly with no significant undulations
Detention basins	Avoid autumn and winter construction when high rainfall rates are to be expected in Europe
Ponds	Ensure that base will retain surface water without significant erosion damage
Stormwater wetlands	As for ponds

(Collated from Woods Ballard *et al.,* 2007b)

I.2. BMP/SUDS Decision Support Systems

I.2.1 Retrofit SUDS selection and design

A flowchart, which is intended to be used by a team of stakeholders who will be working in collaboration, highlights key activities in assessing the feasibility of developing SUDS on a site. The first and second steps in the flowchart are to define the problem and identify the stakeholders. The third step reviews and collects data and determines whether there is sufficient information to evaluate the retrofit SUDS options which are generated in step 4. In step 5, a preliminary appraisal of whether retrofit SUDS are feasible and optimal to achieve the objectives is followed by the design phase in step 6. A decision support framework for the design of retrofit BMP/SUDS was developed by Swan and Stovin (2002) to address unsatisfactory CSO discharges in areas served by combined sewerage systems and was recently modified to be applied to separately-sewered areas draining into combined networks (Sniffer, 2006). It is designed to identify SUDS options and provide hydraulically effective solutions that are cost-effective to implement. Four hierarchies (urban surface type, surface water management train the mode of operation of the device and the cost) have been developed to enable the engineer to examine the range of SUDS options (Table 5). The table directs the user to consider institutional roofs before residential roofs, source controls before off-site controls, infiltration systems in preference to storage based systems and the cheapest options within each category are highlighted.

Table 5: Proposed generic hierarchies for SUDS retrofit selection (Swan and Stovin, 2002)

	Increasing complexity (in terms of detailed design work required) →			
	Urban surface type	Surface water management train	Mode of operation	Cost
Decreasing order of preference ⇩	Institutional roofs Car parks Residential roofs Highways	Source control Conveyance and offsite control	Infiltration Disposal Storage Re-use	Cheapest Most expensive

A case study by Swan and Stovin (2003) of the Meanwood catchment with an area of 55.8 ha, located northwest of Leeds city centre in England and served by a combined sewer system, determined the most cost-effective method of combining recommended retrofit SUDS options. The soakaways option was recommended to disconnect 3.022 ha of roofed area and a swales-based off-site (infiltration basin) option for the disconnection of a further 0.375 ha of roofed area and 2.886 ha of paved area. These options would provide a combined disconnection of 3.397 ha (or 46%) of roofed area and 2.886 ha (or 31%) of paved area. There was an additional option of retrofitting water butts to the remaining 3.973 ha of roofed area contained in the catchment which was not served by infiltration devices. If this proposal was implemented, it would lead to a 68% reduction in the ten year design volume. It was also noted that the proposal would need to be linked to a reduced level of conventional sewer rehabilitation in order to entirely eliminate the flooding problem.

I.2.2 DayWater multi-criteria comparator (MCC)

A system for the selection of BMP/SUDS types has been developed within the DayWater EC-funded project (2002-2005). The Adaptive Decision Support System (ADSS) for Stormwater Pollution Control incorporates a multi-criteria decision making system based on technical, economic, ecological, social and environmental factors, as recommended by ASCE/UNESCO (1998). The DayWater ADSS website address is www.daywater.org and can be accessed with user name 'guest' and password 'guest'. The importance of stakeholder consultation in any significant retrofitting project is shown by the results of using a simplified version of the DayWater components Multi Criteria Comparator (MCC) and Matrix of Alternatives (MoA) in a large housing development project in a village near Cambridge UK, which involves retrofitting part of the existing surface drainage system. This DayWater tool supports end-users in selecting the preferred type of SUDS/BMP for a particular location in relation to a range of site-specific socio-economic and environmental criteria. Photographs of examples of BMP(s)/SUDS from the prototype and a simplified comparison matrix were shown to the stakeholders (Figures 1a, b, c). Each stakeholder was asked to comment on the relative advantages and disadvantages of four stormwater drainage options (infiltration trench, swales, constructed wetland and conventional drainage) and the problems associated with their implementation and maintenance. Following the interview, each stakeholder was asked to complete and return the completed comparison matrix for four drainage options, based on their experience or perception of each option, within one week of the interview. Each drainage option was evaluated separately as the DayWater system does not enable consideration of combinations of BMPs as shown in Figure 3.

Five major instructions were given to the 9 consulted stakeholders:

1. Using the information provided, decide how well you think each drainage option performs against each of the indicators on a scale of 0-4. For example, if you think a particular option (e.g. swale) does not contribute anything towards the indicator (e.g. pollution control) award it a score (S) of '0' (Table 6). If, however, you think that swales offer the best opportunity for pollution control, award them a score (S) of '4'. When developing scores, it is often easiest to decide on the 'best' and 'worst' options with respect to a particular indicator, and then agree on how well the 'intermediate' options contribute to meeting the indicators relative to these identified 'best' and 'worst' options. Ensure your scores always have the same direction i.e. that '0' is the lowest value and '4' the highest one.

Note: Two blank rows have been added to the matrix in case you wish to consider the different drainage options in relation to indicators not already listed.

2. Enter the desired weighting percentages (W), e.g. complete the final column of the matrix with values that reflect the importance you place on each of the 6 criteria. For example,

- flood control: 15%;
- pollution control: 15%;
- environmental impact: 25%;
- amenity and aesthetics: 20%;
- public health and safety: 15%;
- costs: 10%.

Note: If you do not wish an indicator or criterion to be considered within the MCC, allocate a weighting of 0%. The sum of weightings must add up to 100%.
3. Multiply the score for each drainage option by the weighting allotted for that score.
4. Sum the weighted scores (S x W) for each drainage option to give the overall preference score for that option and place this value in the final row.
5. Rate the 4 drainage options according to their total weighted scores with the preferred technique corresponding to the highest (S x W) value.

Table 6: Community Resident Stakeholders. Scores (S) and weightings (W) enabling 4 stormwater management techniques to be rated

	Conventional drainage		**Infiltration trench**		**Swale**		**Constructed wetland d**		**Weightings %**
Indicators	**(S**	**S x W)**	**(S**	**S x W)**	**(S**	**S x W)**	**(S**	**S x W)**	
Flood control	3	45	2	30	3	45	3	45	15
Pollution control	1	15	2	30	2	30	3	45	15
Environmental impact	2	50	2	50	3	75	4	100	25
Amenity & aesthetics	0	0	1	20	2	40	4	80	20
Public Health & Safety, risks	2	30	2	30	2	30	2	30	15
Cost	2	20	1	10	1	10	1	10	10
TOTAL (sum of score x weight)		160		170		230		310	100
Rating (1 low- 4 high)		1		2		3		4	

All nine stakeholders including the two community residents (Table 6) exhibited a clear preference for constructed wetlands, supporting the results of a survey in Scotland of public attitudes towards wetlands and wet retention basins (Apostaki *et al.,* 2001) and the earlier work of Mungur (1997). Of particular interest is the fact that the two urban planners (although working at different municipal levels) rated the four options differently, most notably infiltration trenches which were ranked 2nd by one and 4th by the other. This may indicate that the preferences expressed by stakeholders are not solely determined by either their specific role within a project or their professional training. The outcome of this consultation process was fed-back into the DayWater project with the results being used to update and refine development of the MCC.

I.2.3 BMP Decision Support Model

A survey of 182 drainage sites in Glasgow and Edinburgh, Scotland, indicated appropriate individual BMP techniques or short BMP treatment trains (Table 7) for retrofitting existing drainage systems and for future developments (Scholz, 2007). Glasgow has higher volumes of rainfall runoff and considerably more regeneration sites than Edinburgh, which has a lack of affordable space and will therefore rely on

BMP retrofitting. A BMP Decision Support Matrix was prepared comprising of dominant and supplementary criteria. The dominant criteria include the area available for the BMP and the quality of the runoff and specify the technical conditions for the implementation of the corresponding BMP. The supplementary criteria include catchment size and land value and were weighted by the author and team according to their relative importance for each BMP technique. A trial BMP Decision Support System developed for use with these and other cities is available on the internet at; (http://www.see.ed.ac.uk/research/IIE/research/environ/uw12.html).
'The modelling outcome indicates that ponds (or lined ponds) and permeable pavements are the most frequently proposed BMP techniques for Glasgow and Edinburgh and ponds combined with swales (or shallow swales) are the most recommended BMP combinations (Scholz, 2007).

Table 7 shows some examples of possible treatment train options. A train should be developed that meets design criteria and suits site constraints. Components with a higher capacity can always be substituted and pre-treatment must always be implemented. A number (1) indicates that the system could feature as the first component in the management train for that particular example. If several components are labelled as (1), this implies that any one of them would be suitable for this position (Woods Ballard *et al*., 2007a). Three scenarios A, B and C are shown in Table 7 where the number of SUDS components in the treatment train are 2,3 and 4 respectively. In scenario C for 3 SUDS components, a vegetative filter is followed by a granular filter and either a retention pond or wetland/sand filter.

Table 7: Examples of SUDS treatment trains (Woods Ballard *et al*., 2007a)

	Example	Infiltration	Permeable pavement	Vegetative filtering and detention	Granular filtering and detention	Retention (permanent pond)	Wetland/sand filter	Proprietary oil/silt/debris traps
Number of components:1								
Component sequence	A	1	1	1	1	1	1	
Number of components:2								
Component sequence	A	2	1	1	1			1
	B		1	2		2		2
	C			1	1	2		
Number of components:3								
Component sequence	A		1	3	1	2		
	B		1	1	1	2 + 3		
	C			1	2	3	3	
Number of components:4								
Component sequence	A			1	2	3	4	
	B			4	1	2 + 3		

I.3. Retrofitting stormwater wetlands

I.3.1 Design issues

When considering whether to retrofit subsurface flow (SSF) constructed wetlands into existing urban balancing ponds, the following issues need to be examined (Ellis *et al.,* 2003):

- does suitable access exist or can it be provided?
- can the storage for flood attenuation be safely reduced (at all or enough) so that the 0.6 m deep substrate of a constructed wetland can be incorporated?
- is the outlet structure of the balancing pond offset from the inlet structure? If the outlet is offset (i.e. not directly opposite the inlet) then the flow could short- circuit. Short-circuiting could be reduced by inserting plastic baffles into the substrate to increase flow path length or introducing islands to direct water flows and reduce "dead" zones as well as helping oxygenation (Hall *et al*., 1993).
- does the balancing pond have an impermeable liner? An impermeable lining is necessary to retain a minimum water depth to sustain the plants during periods of no rainfall.

It is anticipated that a constructed wetland retrofitted into an urban stormwater balancing pond will operate as follows:

- initially, as storm flows arrive, the flow will pass through the substrate and therefore subsurface flow treatment will occur.
- if the storm flows continue until the water level in the pond rises above the surface of the substrate, then the constructed wetland will operate as a surface flow system.

An emergent vegetation/open water ratio of about 30:70 should be maintained as a minimum in order to sustain ecological utilisation. This ratio is the minimum threshold for a range of waterfowl and wetland bird species such as mallard, moorhen, coot etc (Hall *et al*., 1993). The wetland development close to the inlet and adjacent fringe will not only be ecologically valuable, but will also enhance metal, hydrocarbon and nutrient removal as well as help conceal unaesthetic changes in water level. A schematic example of a constructed wetland retrofitted into a balancing pond is given in Figures 2, 3 and 4.

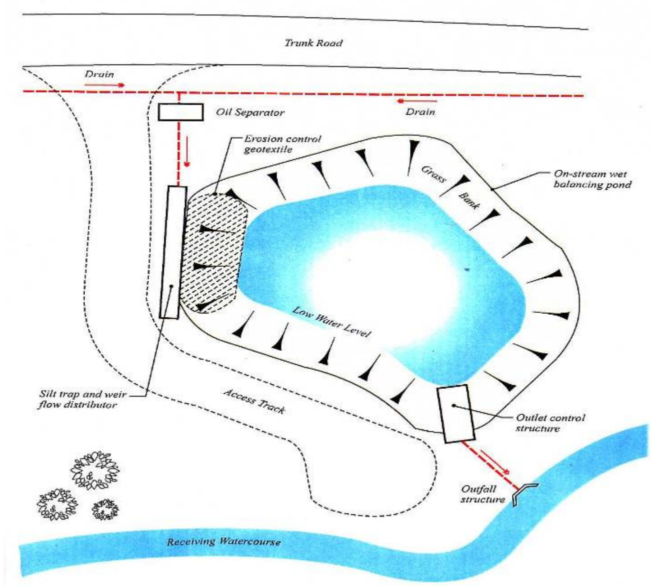


Figure 2: Original on-stream wet retention balancing pond before retrofitting (Lagerberg *et al*, 1998)

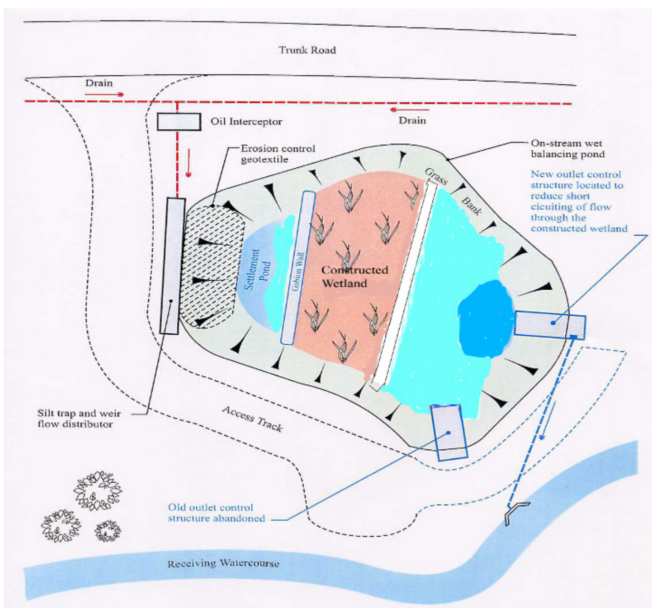


Figure 3: Flood balancing pond following retrofitting to incorporate a constructed wetland (Lagerberg *et al*., 2003)

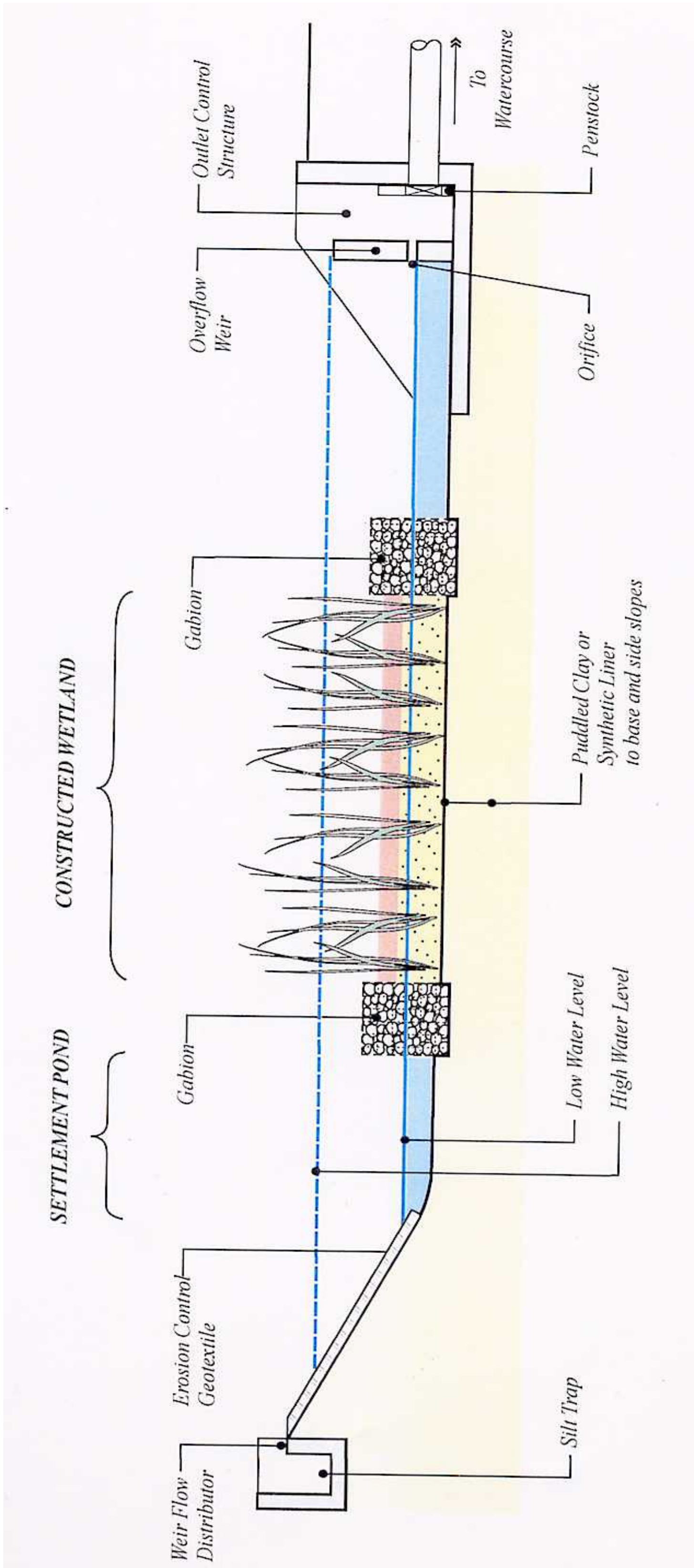


Figure 4: Section through retrofitted constructed wetland

I.3.2 Examples of retrofitted stormwater wetlands

I.3.2.1 North Weald Bassett, east England

Retrofitting of wetlands into existing storage basins can provide opportunities for extending and integrating a range of environmental benefits into SUDS approaches which is illustrated by the flood storage facility located at North Weald Bassett, Essex, east England. An original off-line 38,000 m^3 dry retention basin was constructed here in 1991/1992 to divert flood flows on the North Weald Brook up to the 1:50 storm event which were generated by upstream stormwater runoff from 350 ha of agricultural and residential land use. A 0.5 km box culvert diverted wet weather flows to a 2 ha dry storage basin which provided a drawdown time of 24 hours for the design storm event. The estimated total cost of the original scheme was £1.25M including cost of fees, land purchase and compensation payments. The consultant's report considered that the 1:50 year compensatory flood storage facility provided benefits of nearly £2.5M based on assessed damage to downstream commercial and residential property in North Weald Bassett (Dobbie & Partners Ltd., 1988). The discounted protection benefits excluded consideration of traffic disruption, damage to roads, public utilities/services or costs of emergency services. Thus the total benefit figures (benefit-cost ratio of nearly 3:1), were well in excess of the capital costs of the flood diversion and storage scheme.

The scheme was completed in 1991/1992 with the extended wetland facility being retrofitted by Epping Forest District Council into the dry flood storage basin during 1995/1996 essentially as a community amenity and educational feature. Spoil from the wetland excavation was used to build a small island as a wildlife refuge and to construct embayments on the southern margins of the basin with *Typha*, *Phragmites* and *Scirpus* species being planted to form the wetland vegetation. No consideration was given in this retrofit design to a water quality treatment function for the wetland although it may provide such a further secondary benefit. The original dry balancing basin was already fitted with a sediment trap at the inlet to retain coarse solids and debris prior to discharge into the open basin.

I.3.2.2 The Wharrage Wetlands, Redditch, England

A series of retrofitted facilities has been built by the Environment Agency for England and Wales Midlands Region into the existing flood plain of the Wixon Brook to store and treat contaminated storm runoff from a 4 km^2 urbanised catchment within which 65% of the area is occupied by residential, industrial and highway surfaces. The retrofitted system utilises pools and cut-off meanders to construct storage ponds and reed beds. The wetland train consists of a 0.198 ha upper silt and oil trap, a 0.369 ha middle flow and quality balancing pond with marginal planting, and a final 0.214 ha stabilisation and treatment *Phragmites australis* reed bed; a total 3,500 m^3 storage and treatment facility being provided. The excavated silt and spoil has been used to landscape the adjacent river corridor to provide valuable ecological micro-habitats for wildlife and amenity development including the construction of an artificial badger sett.

I.3.2.3 Newbury By-pass, England

A horizontal sub-surface flow system adjacent to the A34 Newbury By-pass, UK (opened in November 1998) was retrofitted into a vegetated balancing pond preceded by an oil separator, silt trap, grass filter and settling pond (Figure 5). Thus, although

the pond is a sub-surface flow system, its size and layout means that storm flows will over-top the substrate and therefore turn the system from sub-surface flow to surface flow part way through an intense storm event. The constructed wetland within the pond was planted with an initial section of *Phragmites australis* followed by *Typha latifolia*. A vegetated balancing pond, which also contains an oil separator and silt trap but has no preliminary settling basin, was adopted as a control pond (Figure 6). The slope and depth of this pond was graded and it was planted with a mixture of floating, emergent and submergent species.

Figure 5: Retrofitted constructed wetland, Newbury By-pass, UK

Figure 6: Vegetated balancing pond, Newbury By-pass, UK

I.3.2.4 Retrofitted in-stream constructed wetland, Dagenham, England

This site is located on a small watercourse which receives substantial runoff from the surrounding urban catchment area. The system is 250 m long and is built in a specifically widened area of the stream. It consists of a settlement tank, followed by a series of three beds separated by weirs which control flow (Fig 7). The first bed is planted with *Typha latifolia*, and the second and third beds with *Phragmites australis*. Typha has been damaged by the grazing of horses introduced illegally to the adjacent park (Figure 8). Both Typha and Phragmites seedlings were planted in February-

March when high flow rates and water levels occurred resulting in poor establishment of the plants and, in particular, Phragmites. The choice of planting months was influenced by budget availability. The system was effective at reducing suspended solids and aqueous metal concentrations but there is a need to raise public awareness of toxins in the sedimentation tank and the role of the plants in order to enhance its efficiency.

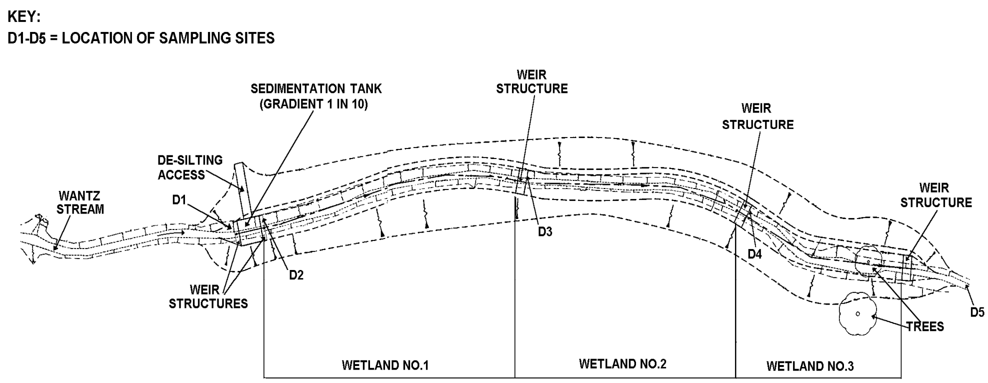


Figure 7: Diagram of a retrofitted in-stream constructed wetland system.

Figure 8: Limited establishment of *Typha latifolia*, Dagenham, UK

I.3.2.5 Welsh Harp Reservoir, north-west London

The Welsh Harp Reservoir is a body of open water (96 ha) located in north-west London, which was constructed in the mid-nineteenth century to provide water for two canals and to act as a flood alleviation basin (Figure 9). The area surrounding the reservoir was originally countryside but is now urbanised. The original open water has been reduced by the growth of reedbeds, marshlands, willow carr woodland and grassland which provide habitats for resident and over-wintering waterfowl populations and the reservoir was designated a Site of Special Scientific Interest (SSSI) in 1950.

The Welsh Harp is fed by the Silkstream in its northern arm and the Dollis Brook from the east. Both streams receive urban runoff and the downstream sediments become increasingly contaminated and sediment remobilisation during storm events and transport into the reservoir presents a threat to organisms including macro-invertebrates and via the food chain, fish and waterfowl. Retrofit oil booms have been installed at the inlet of both streams and at the Silkstream inlet, a trash screen and automated `grab' collector has been added. The oil boom consists of an inflated plastic cylinder with a skirt protruding below the water surface to provide additional oil retention during storms. Initial monitoring by Jones, (1995), a year after its installation, showed a reduction in hydrocarbon concentrations in the water immediately below the oil boom on the Silkstream but negligible reduction in sediment concentrations. The extremely effective natural treatment processes which occur within the Welsh Harp basin are clearly demonstrated by the 50%-80% reductions recorded in both water and sediment mean total hydrocarbon levels and 97% reduction in suspended solids between the boom and the confluence of the upper limb of the Welsh Harp with the Brent reservoir.

Figure 9: Welsh Harp Reservoir, north-west London, UK

I.3.2.6 Caw Burn, Scotland

The Caw Burn retrofit SUDS is located near Livingston, West Lothian, central Scotland in the headwaters of the Caw Burn catchment (2.08 km^2). These comprise surface water runoff from the Houston Industrial Estate, where construction commenced in the 1960s, and two residential areas. The catchment headwaters are separately sewered and the surface water runoff is drained through a large culvert (1.8 m high x 3.6 m wide) before emerging as the Caw Burn. The design requirement for SUDS was the treatment of year-round dry weather flow plus the first flush during storm events.

The SUDS contains two components: an initial main settlement pond and a vegetated overland flow zone (wetland). The main settlement pond was designed to trap floating hydrocarbons and to allow sedimentation of grit and some silt particles. The diverted flow enters the main settlement pond through an inlet structure comprising gabions filled with crushed rock lying above a rip rap apron to diffuse flow. The pond has a design surface area of 891 m^2 and depth of 0.6 m. Planting of marginal vegetation on the shelf (270 m^2) to the east of the pond was intended to help begin the process of

BOD removal. Water from the main settlement pond passes into the overland flow zone through a gabion baffle wall (containing crushed rocks and concrete kerb stones) designed to trap hydrocarbons in all flow conditions. The overland flow zone was designed to remove fine particulates and associated metals and hydrocarbons by filtration through the plant litter layer and to remove BOD by biological filtration. It appears to have been created by constructing an earth bund adjacent to the Caw Burn to raise water levels in an existing area of impeded drainage. Water from the overland flow zone flows into a planted swale and then into an outlet ditch which conveys it back to the main Caw Burn channel. There is no evidence of a liner for the SUDS and there has apparently been minimal maintenance since construction.

The original SUDS design described by Marland (1997) was compared with the good practice guidelines for SUDS wetlands and retention ponds given in the CIRIA Sustainable Urban Drainage Systems design manual for Scotland and Northern Ireland, C521 (CIRIA, 2000; Heal et al., 2007) (Table 8). At best, when all components of the Caw Burn SUDS are considered, the system provides less than 15% of the storage volume and less than 1% of the retention time recommended for equivalent SUDS structures in the CIRIA manual.

Table 8: Comparison of the design storage volume and retention time of the different components of the Caw Burn SUDS with the CIRIA manual guidelines (Heal et al., 2007)

	Storage volume (m^3)	*Retention time (days)*
Caw Burn settlement pond	610	0.017
CIRIA guidelines for retention ponds	34536 (4 x Vt)	14-21
Caw Burn settlement pond as % of CIRIA guidelines	1.8	0.1
Caw Burn wetland	3248	0.008
CIRIA guidelines for wetlands	25902	14
Caw Burn wetland as % of CIRIA guidelines	12.5	0.06
All Caw Burn SUDS	3858	0.025
Average CIRIA guidelines for detention basins/wetlands	30219	14
All Caw Burn SUDS as % of CIRIA guidelines	12.8	0.2

I.4. Retrofitting of drainage systems in cities and regions

The European Water Framework Directive is the main driver behind the review of drainage systems by European cities. The review of the drainage systems and the selection of BMPs in the cities of Edinburgh and Glasgow, Scotland by Scholz (2007) have previously been discussed. Other European cities and towns with innovative drainage systems have been listed by D'Arcy and Chouli, (2007) and the retrofitting of drainage systems has been introduced by the following examples.

I.4.1 Dublin, Ireland

The Greater Dublin Strategic Drainage study recommended the use of SUDS to be greatly increased in the region (Doyle *et al.,* 2003). It had been suggested that Ireland might not be able to meet its obligations under the Water Framework Directive without the widespread use of SUDS. Doyle *et al.,* (2003) emphasise that, in addition to the benefits of stormwater control and the prevention of flooding, SUDS will bring benefits to developers as well as the public by enhancing the value of existing and new properties. On the river Tolka which is prone to flooding, retrofit wetlands have been introduced since 2001 on problem surface water sewers prior to discharge to the river (D'Arcy and Chouli, 2007).

I.4.2 Dunfermline, Scotland

Using the ranking system of Swan and Stovin (2002) which highlights institutional roofs as most feasible for SUDS, and highways as least feasible, 29% of the total catchment areas of Dunfermline were considered to be suitable for SUDS retrofit (Hyder Consulting, 2004). The impermeable area of the catchment would be reduced from 55% to 45% if the SUDS retrofit potential of these areas was realised. Targeting roads and residential roofs by source control measures would reduce the impermeable areas contributing to surface water runoff. The Dunfermline area has a significant amount of green space available that could be utilised for SUDS techniques such as detention/attenuation ponds. A potential disadvantage is the limited potential for infiltration of the clay soils.

I.4.3 Malmo, Sweden

Augustenborg is an inner city suburb of Malmo, southern Sweden which previously experienced flooding during heavy storms from CSOs. An open stormwater system was introduced in 2001 and drainage by the combined sewer system was disconnected. Stormwater now passes through a complex system of green roofs, swales, channels (Figure 10), detention ponds (Figure 11) and small wetlands, Villarreal et al. (2004). Community participation was an important factor in the implementation of stormwater disconnection.

Figure 10: Ornamental surface drain, Augustenborg, Malmo, Sweden

Figure 11: Combined amphitheatre and stormwater detention pond, Augustenborg, Sweden

I.4.4 Nijmegen, Netherlands

The Nijmegen Water Plan (1997) aimed to disconnect 20% of paved surfaces in urban areas within a decade. Examples of pervious road surfaces and combined grass swales and infiltration trench systems are shown in Figures 12 and 13 respectively. Visual water arts projects have also been implemented to raise public awareness of stormwater.

Figure 12: Aquaflow pervious road surface, Nijmegen, Netherlands

Figure 13: Combined grass swale and infiltration trench system, Nijmegen, Netherlands

I.4.5 Emscher, Germany

Emscher is a region (named after the river) which is drained by surface water channels that act as combined sewers. The system is currently being replaced over a period of 15 years with sanitary sewers and to retrofit source-based stormwater management systems where feasible. The total amount of stormwater carried by the system is aimed to be reduced by 15%. A GIS-based planning tool highlights and prioritises the feasible level of disconnection in each area.

I.4.6 Tokyo, Japan

An Experimental Sewer System (ESS) incorporating infiltration and storage systems in the sewerage network has proved an effective stormwater runoff control system in a dense urbanised area of Tokyo (Fujita, 1997). Footpath pavements in Tokyo are being changed to permeable pavements and residents construct soakaways in their own housing areas at their own expense. The infiltration trench is so effective that it has been used in various locations such as housing sites and public gardens and 285 km were constructed in Tokyo from 1983-1995.

I.4.7 Portland, USA

The City of Portland Environmental Services website (www.portlandonline.com) provides advice to the public on its Sustainable Stormwater Management programme including downspout disconnection from houses. Files describing demonstration projects such as the stormwater retrofit of a street with a planted curb extension of an existing residential collector may also be downloaded (Figure 14). The goal of this project was to maximise the retention, treatment and infiltration of street runoff, while providing improved safety and a visual amenity for the neighbourhood Public awareness of stormwater management has also been enhanced by an annual calendar illustrating examples of sustainable stormwater systems and this is available from the website.

Figure 14: Street curb extension, Portland, USA

II. Review of BMPs in relation to their potential to contribute to other sectors of the urban water cycle

II.1. Introduction

The current and potential role of BMPs in drinking water supply and demand; sewage treatment and benefits to other aspects of the environment; ecological, aesthetic, recreational and social amenity and to environmental education will be addressed in this report. The report contributes to meeting the following objectives of the SWITCH project;

Theme 2: Stormwater management
Objective 2.2**:** To develop concepts of sustainable stormwater resource use which cities can utilise for their own stormwater management strategies.

Theme 3: Efficient water supply and water use for all
Objective 3.2: To develop and demonstrate sustainable treatment (and storage) technologies for the promotion of safe water reuse.

Theme 5: Urban water environments and planning
Objective 5.4: To assess and maximise the use of natural systems and processes for the effective management of water supply, sanitation and urban drainage services and of the urban water cycle as a whole.

The following related deliverables of SWITCH Theme 2 provide some of the many examples of BMPs fulfilling the roles outlined in this report;
D2.2.1b: Catalogue of Options for the Reuse of Stormwater
D2.1.4 Part B (section I): Review of BMPs in relation to their potential to integrate with existing infrastructure (i.e. retro-fit/hybrid systems)

This report is structured with eight sections which address the various roles of BMPs. Examples of individual BMPs which fulfil these roles are included in each section and there may be more than one role for some of these examples. Furthermore, the potential for additional roles is considered, for example in providing Biodiversity and landscape enhancement for a BMP which functions primarily for wastewater treatment.

As an initial focus, a summary of the multiple applications of stormwater reuse involving some use of BMPs in countries throughout the world is shown in Table 1 which was previously included in D2.2.1b. The imbalance between these applications in less economically developed and economically developed countries, indicates the potential for the role of BMPs in stormwater source control and reuse. Table 2 in this report summarises the current and potential roles of BMP types for drinking water supply, irrigation, wastewater treatment, landscape and biodiversity enhancement, social, amenity and environmental education. However, the decisions (Yes or No) in the table are intended to provide a basis for discussion and are not therefore inflexible.

Table 9: Stormwater reuse in examples from different countries and continents

Stormwater reuse	Africa	Australia	Brazil	China	Germany	India	Singapore	Sri Lanka	Thailand	UK	USA
Aquifer recharge and reuse (artificial process)											
Groundwater recharge (natural process)	x			X							
Rainwater harvesting for drinking water	x		X			X	X	x	x		
Rainwater harvesting for non-potable use in homes e.g.											
* garden watering	x	X	X	X	x					x	x
* toilet flushing	x	X	X	X	x	X	X	x	x	x	x
* hot water	x	X	X		x	X	X	x	x	x	
* car washing	x	X			x						
Rainwater harvesting for industrial uses e.g.				X							
* cooling towers		X		X	x		X				
* cleaning processes					x		X				
* electricity generation		X		X	x			`			
* toilet flushing					x		X				
Irrigation e.g.											
* grazing lands	x	X									
* crops		X									
* golf course		X		X							
* parks										x	x
Creation of artificial water bodies e.g.				X							
* lakes		X		X						x	x
* wetlands		X		X						x	x
* ponds		X		X						x	x
Recharge of natural wetlands	x	X									
Commercial vehicle washing				X	x						
Fire fighting											

Table 10: Roles of BMP types

BMP type	Drinking water supply	Irrigation	Wastewater treatment	Landscape & Biodiversity Enhancement	Social, Amenity & Education
Green roofs	No	Yes	No	Yes	Yes
Soakaways	No	Yes	No	No	Yes
Water butts	Yes	Yes	No	No	Yes
Rainwater harvesting	Yes	Yes	No	No	Yes
Filter strips	No	No	No	No	Yes
Infiltration trenches	Yes	No	No	No	Yes
Swales	No	Yes	No	Yes	Yes
Bioretention	No	No	No	Yes	Yes
Pervious pavements	No	No	No	No	Yes
Geocellular systems	No	No	No	No	Yes
Sand filters	Yes	No	Yes	No	Yes
Infiltration basins	No	Yes	Yes	Yes	Yes
Detention basins	No	Yes	Yes	Yes	Yes
Ponds	Yes	Yes	Yes	Yes	Yes
Stormwater wetlands	No	Yes	Yes	Yes	Yes

II.2. The role of BMPs as a source of drinking water

The examples in this section are selected from SWITCH report D2.2.1b. Examples of rainwater harvesting (RWH) using water butts and jars, above and underground storage tanks and cellars are included. Tank size varies depending on the user group and households may need a tank from $1m^3$ to more than $40m^3$ depending on the number of persons and their economic status. Rainwater supply from roofs depends on the annual rainfall, the roof surface and the runoff coefficient. For example, a metal sheet roof of area $80m^2$ will supply 800 (annual rainfall in mm) x 80 (roof area in m^2) x 0.8 (runoff coefficient) = 51,200 litres/year. A commonly accepted minimum water demand is 20 litres per person per day, or 20 x 365 = 7300 litres per year, therefore a household of seven persons could be provided by the roof in the example.

The drinking water quality regulations and standards in less economically developed countries are normally less stringent than in developed countries, where further treatment of harvested rainwater may be required. Furthermore, public opposition to the use of stormwater as a source of drinking water may be considerable in the latter and require a protracted campaign of public information and discussion.

II.2.1 Accra, Ghana

In Ghana, rainwater has historically made significant contributions to the water supply requirement of all urban and rural communities. The supplies of the Ghana Water Company Ltd (GWCL) do not meet the demands of the city. The people in the city harvest rain as much as they can whenever it rains for domestic uses such as drinking, washing, cooking, flushing of toilets etc. The Ministry of Water Resources, Works and Housing together with the Ghana Science Association and some NGO's have started to raise awareness of the benefits of rainwater harvesting (RWH). The government is in the process of passing legislation requiring all houses to incorporate rainwater harvesting schemes requiring water storage butts and tanks (IWMI, 2006).

II.2.2 Katsukunye, Zimbabwe

Katsukunye, which is located approximately 170 km from Harare, Zimbabwe, was well known for perennial water shortages. As the functioning of the local school and clinic was becoming adversely affected, the Ministry of Health and Child Welfare was on the verge of closing them down. However, the community's endeavour to harness rainwater and evolve rules for its sustainable management has prevented these closures. As a consequence, about 120 people in the clinic and 700 students in the school are benefiting from the supplied water. In order to avoid future conflicts over the limited amount of water, a water users committee has been formed including members from the village, school and clinic. A demand management protocol was also formulated to allocate water as per user needs. In this situation, RWH has proved to be a reliable option in an area with serious water shortages.
www.rainwaterharvesting.org/catchwater/april-may2003/partnership_news.htm

II.2.3 Rakai, Uganda

Rakai is located in the southern hills of Uganda and has a tropical bimodal climate. Small (700 litre) jars (Figure 15) have been made by a women's group to collect water from roofs and supplement their potable and non-potable water needs. The jars cost less than US$70 each to produce.
www.ircsa.org/factsheets/lowincome.htm

Figure 15: Water storage jar, Rakai, Uganda

II.2.4 Salisbury, Adelaide, South Australia

In this residential development, the household RWH system (gravity and pressure systems) has a 150 m^2 design roof area for a two person dwelling. Water demand is estimated at 500 l/day and the rain tank capacity is 4500 l (Figure 16). The Australian guidelines for the use of recycled water for direct or indirect augmentation of drinking water supplies were published in May, 2008.It is one of a range of guidelines for water reuse either published or in preparation, which aim to provide a scientific basis for implementing decisions on water reuse in a safe and sustainable manner.
www.ephc.gov.au/ephc/water_recycling.html

Figure 16: Water storage tanks, Salisbury, Adelaide, Australia

II.2.5 Petrolina, Brazil

Petrolina is in the semi-arid belt of north east Brazil. Rainfall is low and varies from year to year. Tanks with 1-2 kl capacity are used to store water for potable and non-potable use by each household (Figure 17). They are usually provided by NGOs as the cost, starting from US$200 per tank, is unaffordable by the local population. www.ircsa.org/factsheets/lowincome.htm

Figure 17: Water storage tank, Petrolina, Brazil

II.2.6 Dongtan City, near Shanghai, China

Dongtan will be a new ecocity for 500,000 people on the 120 km long Chiongming Island in the estuary of the Yangtze river, 15 km north of Shanghai (Figure 18). The city will be developed on 630 ha of mostly agricultural land. The first phase will be completed by 2010 but the whole city will take 40 to 50 years to build. Human sewage will also be composted greatly reducing the use of water in its treatment. Rainwater will be captured and stored in canals and water features around the city as well as in reservoirs and there will be processes to purify it**.** (Ove Arup, 2007).

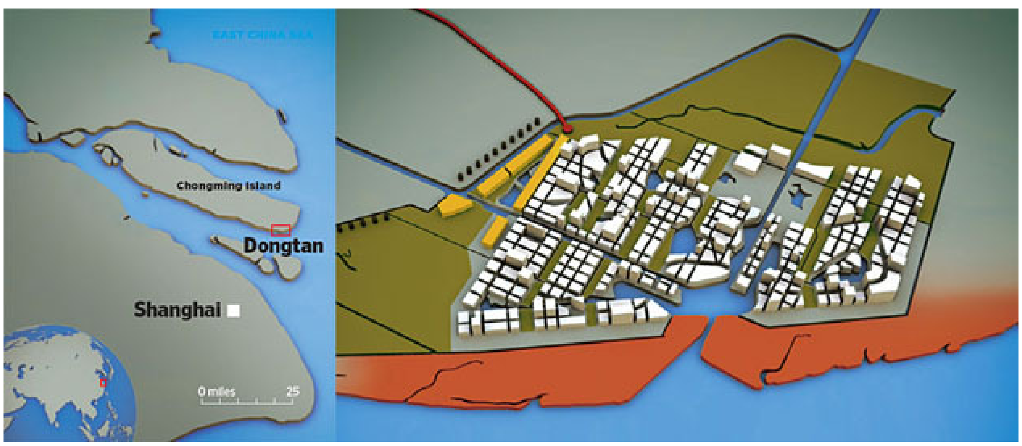


Figure 18: Location and design of Dongtan City, China

II.2.7 Gansu Province, China

Gansu Research Institute for Water and Conservation (GRIWAC) installed 23,000 updated traditional underground water cellars (shuijao) by the end of 1994. Each cellar (15-20 m^3) was associated with 100 m^2 of new catchment and a domestic water supply was secured for a total of 140,000 people. By 2006, 2 million shuijao built or upgraded in the previous 15 years, were helping to solve the water supply problems of 15 million people and supporting the irrigation of 2.6 million hectares (McCann, 2007).

II.2.8 India

Raincentres are being established throughout India by the Centre for Science and the Environment to provide people with information on how to harvest rain. Local Non Government Organisations (NGOs) and citizens' groups are identified as partners to

disseminate water literacy. Groundwater level monitoring in 11 model projects has shown the impact of rainwater harvesting on improved quality and quantity of groundwater. www.rainwaterharvesting.org/raincentre.htm

A Water Harvesting Manual for Urban Areas provides information on how to decide whether to store or recharge water in relation to the rainfall patterns in a particular region and the design of appropriate systems. In Delhi, Rajasthan and Gujarat, where the total annual rainfall occurs during 3 to 4 months, recharge is usually practiced. In Kerala, Bangalore and Tamil Nadu, where the rain falls throughout the year, a small sized tank is appropriate for each household.
www.rainwaterharvesting.org/Urban/Howtoharvest.htm

II.2.9 Badulla, Sri Lanka
The town of Badulla is located in a hilly area of Sri Lanka and experiences a tropical, bimodal climate. Rainwater is used as a main water source and groundwater sources are few and tend to be at the foot of the hills. To reduce the burden of carrying water, the local authority provided 5,000 l ferrocement tanks at a cost of about US$150 per tank, which are used to collect water from roofs for most household water supply (Figure 19). The tanks are now being adopted nationwide for use in areas where access to other protected water sources is difficult.
www.ircsa.org/factsheets/lowincome.htm

Figure 19: Water storage tank, Badulla, Sri Lanka

II.2.10 Khon Kaen, Thailand
Khon Kaen is located in north east Thailand and experiences a tropical monsoon climate. The "Thai jar", with a capacity of 1-2 kl, was selected for one of the world's largest roofwater harvesting projects (Figure 20). The jars were produced commercially on a large scale and for less than US$30 per jar, thus enabling the purchase of the jars throughout the population.
www.ircsa.org/factsheets/lowincome.htm

Figure 20: Water storage jar, Khon Kaen, Thailand

II.2.11United Kingdom (UK)

The previous examples of rainwater being used as a source of drinking water are, with the exception of Australia, located in less economically developed countries. In the UK, concerns about the reuse of rainwater are summarised in Table 3.

Table 11 Stormwater reuse: concerns and management advice; UK

Concerns	**Current management advice**
Public health and safety	• Potable use of rainwater not currently recommended [1] • Correctly collected and stored stormwater can be used in washing machines and toilets without further treatment [1]
Size of tank	• Typical tank size for a 4 person home is 2 m^3 [1]
Mosquitoes/ contamination	• Cover tanks to exclude mosquitoes, birds, animals and sunlight [2] • Check roof is clean and not made of toxic metals or asbestos [3]
Legal requirements	• No regulations relating to the water quality for WC and washing machine use [1] • Mains water backup must be in accordance with the Water Supply (Water Fittings) Regulations (1999) [1]
Costs	• Businesses qualify for Enhanced Capital Allowance Scheme [4] • Installation more cost attractive in new developments[1]

Sources: [1] Environment Agency for England and Wales (2006a); [2] Your Home: Technical Manual (2005); [3] Centre for Alternative Technology (2006); [4] UKRHA (2006)

II.3. The role of BMPs in irrigation

The four examples in this section are selected from SWITCH report D2.2.1b. Melbourne Cricket Ground, Sydney Olympic Park, Australia and the Beijing National Stadium, China are examples of large scale developments which have adopted the latest water reuse technology and systems for the irrigation of grass and green space. Chongqing University, China is developing greywater and rainwater reuse systems as part of a SWITCH demonstration project at a new campus. If the Chongqing University systems are adopted in other Chinese cities, there is a considerable potential for a national reduction in potable water consumption.

II.3.1 Melbourne Cricket Ground, Australia

Melbourne Cricket Ground (MCG) has been upgraded into a 100,000 seat modern day stadium (Figure 21). The drainage system includes diversions, storage tanks, pumps and disinfection. Water reuse options include pitch and adjacent parkland irrigation. These measures enhance the image of the MCG as an environmentally responsible and sustainable venue as well as going a considerable way to meeting the Victoria State Government's Ecologically Sustainable Development (ESD) Guidelines for venues that were utilised for the Melbourne 2006 Commonwealth Games. (Ove Arup, 2007).

Figure 21: Melbourne cricket ground, Australia

II.3.2 Sydney Olympic Park, Australia

Water Reclamation and Management Scheme (WRAMS). The design of Sydney Olympic Park (SOP) is based on the concept of an integrated urban water cycle and includes land rehabilitation, flood alleviation, aquatic habitat restoration, stormwater storage and reuse, pollution control and recreational provision. Thirty different constructed wetlands have been created onsite, a water storage basin has been developed in a disused brick pit and the main stadium has 3Ml/d storage for rainwater. The source of reclaimed water is a 'sewer mine' supplemented by surface runoff from the brick pit. Water use at SOP is 48% recycled, 46% direct stormwater reuse and 6% potable. Of the recycled water, 60% is used for irrigation and washdown. www.sydneyolympicpark.com.au

II.3.3 Beijing National Stadium, China

This new build stadium has a capacity of 90,000 and has been used initially for the 2008 Olympic Games (Figure 22). A rainwater system designed for water saving is incorporated in the national stadium. Rainwater is collected from the field of the main stadium, roof of the stadium, warm-up field and the surface around the stadium before being transported to reservoirs. After being processed to meet the Regenerated Water Quality Standard for the 2008 Olympic Games National Stadium, recovered rainwater is reused for irrigating green areas and other uses. The total recovered rainfall is estimated to be about 61,000 m^3/year, representing 24% of the annual reused water volume for the stadium. This system will significantly lessen the burden on decreasing water resources in Beijing City (Ove Arup, 2007).

Figure 22: Beijing National Stadium, China

II.3.4 Chongqing, China

The site of Chongqing Greywater demonstration project will be located in the New Huxi Campus of Chongqing University (CQU). There are two large lakes in the teaching area, and one in the residential area. In the first phase, about 250,000 m^2 of buildings have been constructed. The grey water from 21 high-rises will be collected and treated onsite by a constructed wetland (CW), the rainwater will be captured and treated onsite with shallow grass trenches, swales and CWs (Figure 23). The reclaimed water (both grey water and rain water) will be used as the source of green space irrigation and will complement the lake water. The grey water demonstration project for the new campus of CQU will reduce the consumption of potable water by 150 million litres per year. If this project can be replicated at 10 sites in each city in China, it will reduce the consumption of potable water by 990 billion litres per year, which will reduce by 2.5% the future water supply shortage in China (SWITCH, 2007).

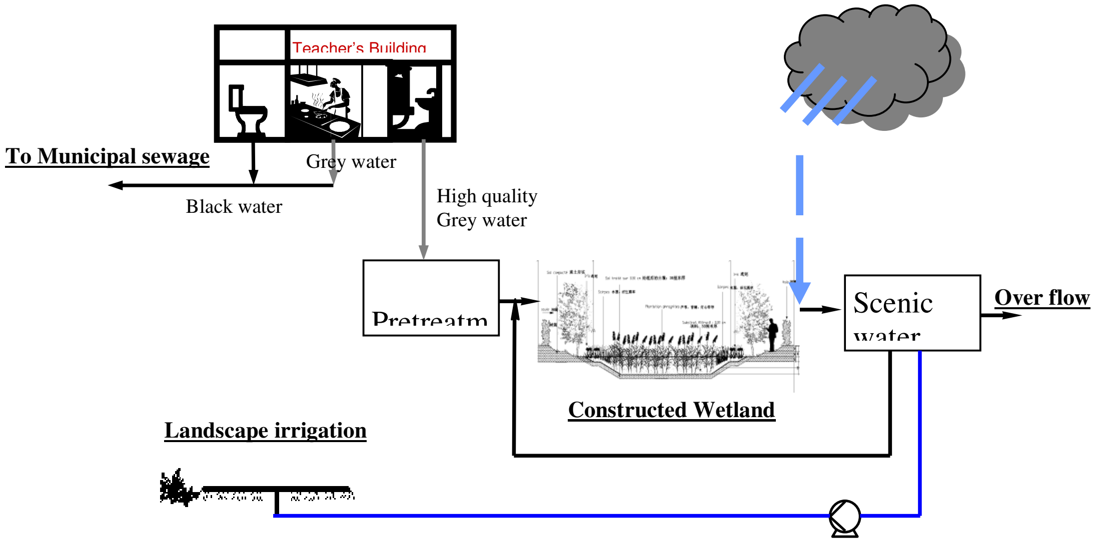


Figure 23: Flow diagram of sustainable water system in new campus, CQU

II.4. The role of BMPs in domestic wastewater treatment

Constructed wetlands have been introduced to countries throughout the world to treat different types of wastewater including predominantly domestic wastewater or sewage. The types of design include horizontal surface flow or freewater surface and sub-surface flow systems, vertical flow systems and hybrid combinations of horizontal and vertical flow systems. In small communities, separate sewage may be entirely treated by constructed wetlands, whereas in urban environments, constructed wetlands are normally used to partially treat separate or combined sewage, providing secondary or tertiary treatment. The following examples illustrate different types, sizes, locations and treatment applications of constructed wetlands.

II.4.1 Little Stretton, England, UK

A horizontal sub-surface flow constructed wetland arranged in a series of eight trapezoidal terraced beds (12 m long and 2 m wide) with a 12 mm pea gravel substrate, was developed in 1987 to treat domestic wastewater from 15 dwellings and 2 farms in Little Stretton in central England (Figure 24). The system was designed with 3 m^2 per person equivalent (p.e.), and a predicted average flow of 10.2 m^3/day that was exceeded by the subsequent connection of surface water drains to the system. The Environment Agency for England and Wales set a descriptive discharge consent for this system with no numeric values, The system is monitored by Severn Trent Water, the authority responsible for its design and operation. Due to the highly variable concentrations of the farm parlour washings, the farm effluent was disconnected and treated separately.

Severn Trent Water has introduced more than 200 constructed wetland systems for primary, secondary and tertiary treatment of both separate and combined sewage. The possible toxic effects of heavy metals in separated stormwater on the plants can be seen in the left bed in Figure 25 , with etiolated and discoloured plants in comparison to the healthy green plants on the right bed that are treating separated secondary treated domestic wastewater.

Figure 24: Constructed wetland, Little Stretton, Leicestershire, England, UK

Figure 25: Constructed wetland for stormwater (left) and separate sewage treatment (right)

II.4.2 Germany

A horizontal sub-surface flow constructed wetland for the treatment of domestic wastewater being discharged from a farm providing accommodation for visitors is shown in Figure 26. Winter dieback of the reeds is apparent but their patchy distribution is a consequence of premature harvesting before the plants had reached maturity. Below the wetland is a final settlement pond which receives the effluent discharge from the wetland.

Figure 26: Constructed wetland treating domestic wastewater, Germany

II.4.3 Shenzhen City, China

In Figure 27, pre-screened domestic wastewater is treated by a series of rectangular horizontal sub-surface flow constructed wetlands, each of which is planted with a different species. The red and orange flowers of Canna can be seen in the background. The landscaping potential of the design of these wetlands has not been realised. The effluent from the wetlands is used for irrigating the park during the day when the park receives visitors. However, the health risk of this practice is a cause for concern and

emphasises the importance of monitoring constructed wetland effluent for bacterial and viral populations.

The piped distribution of domestic wastewater in a vertical flow constructed wetland near the city of Shenzhen, is seen in Figure 28(a). The treated effluent is subsequently discharged to the Shantian river. This system is experimental and each cell has a different plant species but data on its performance are limited. However, the healthy condition of the mature Canna plants in Figure 28(b) is a positive indicator.

Figure 27: Constructed wetland, Shenzhen Park, South China

(a) **(b)**

Figures 28 (a) and (b): Constructed wetland, Shenzhen, China

II.5. The role of BMPs in the treatment of mine wastewater

The following examples illustrate the potential of constructed wetlands for the treatment of mine drainage and the need to select an appropriate type of wetland to match both the water quality and quantity objectives of the treatment. In the first example, the size of the system was inadequate for the treatment demand and in the second example the type of constructed wetland was inappropriate.

II.5.1 Wheal Jane Mine, Cornwall, UK

A constructed wetland was developed in the 1990s as part of a pilot bioremediation system for the treatment of acid drainage from a disused mine in southwest UK (Figure 29). The horizontal sub-surface flow wetland was designed to remove iron hydroxide/oxyhydroxide and arsenic from the mine drainage. It was combined with a an anaerobic cell designed to remove zinc, copper, cadmium and iron by the bacterial reduction of sulphate and an aerobic rock filter designed to remove manganese by promoting algal growth. The pilot passive treatment system was effective but in order to meet the treatment demand, it has essentially been replaced by an active treatment plant, comprising a high-density sludge alkali dosing plant, which during its first full winter of operation treated a total of 4400 million litres of water.

Figure 29: Construction of treatment wetland, Wheal Jane Mine, Cornwall, UK

II.5.2 Mai Mo Mine, North Thailand

Five surface flow constructed wetlands, each <100 m long, were introduced to a lignite strip mine in Mai Mo, North Thailand in order to reduce the concentrations of sulphate in effluent discharges from settlement ponds to the receiving river (Figure 30). The selection of surface flow constructed wetlands, by an international consultancy company was inappropriate and sulphate concentrations were not adequately reduced. In contrast, the deeper layer of the substrates of sub-surface flow constructed wetlands would provide anoxic conditions and the reduction of sulphate. This example highlights the importance of scientists as well as engineers, in the selection and design of constructed systems for treating industrial wastewater

Figure 30: Constructed wetland treating mine wastewater, Mai Mo, Thailand

II.6. The role of BMPs in landscape and biodiversity enhancement

In Table 10, seven of the fifteen types of BMP are shown to have the potential to enhance landscape and biodiversity. The BMPs range in size from compact or pocket wetlands to large constructed wetlands but each has the potential, if appropriately designed, to make a beneficial visual and aesthetic impact on the environment. The following examples are arranged in two sub-sections; urban highway BMPs and urban green space BMPs to illustrate the diversity of location, size and design.

II.6.1Urban highway BMPs

II.6.1.1 Australia

A Water Sensitive Urban Design (WSUD) programme has been introduced to Australian cities. Bio-retention beds to trap sediment, nutrients and other pollutants from road runoff have been created in locations including Cremone Street, Richmond, in the state of Victoria (Figure 31). Rocks are placed at the kerb entry points to distribute flows evenly across the bio-retention basin and prevent erosion. The water slowly permeates through the filtration medium to a series of slotted pvc pipes located at the base of the basin, that discharge the filtered water to the existing drain under the kerb and channel. A high flow bypass drainage pit (raised 50 – 100 mm above the base of the basin) is located in every system to divert floodwaters directly into the existing main drain. An adjacent signboard explains the design and function of the bio-retention beds. Another example of interpretation of design and function of BMP/SUDS is shown in the signboard for the car park in Newcastle, New South Wales. This system provides infiltration and piped drainage to a natural channel from the grassed surface of each parking space (Figure 32). A landscaped bio-retention system in an area of open space between two roads has been constructed in Kingston, a suburb of the city of Melbourne (Figure 33). Pocket wetlands or roadside bio-retention systems which are complemented by a porous road surface have been introduced in Manly, New South Wales (Figure 34).

II.6.1.2, Germany, USA, UK

Similar systems are shown in Berlin, Germany designed by IPS Consultants, a SWITCH partner, and Portland, Oregon, USA (Figures 35 and 36), and a porous road surface with an infiltration trench bordered by landscaped plants, is shown in a supermarket car park in Scotland, UK (Figure 37).

Figure 31: Pocket wetland and interpretive signboard, Richmond, Australia

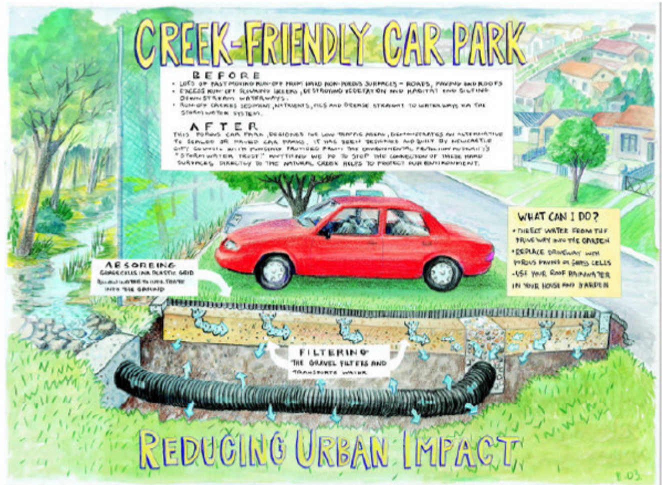


Figure 32: Interpretive signboard, Newcastle, Australia

Figure 33: Bio-retention system, Kingston, Melbourne, Australia

Figure 34: Pocket wetlands and porous road surface, Manly, NSW, Australia

Figure 35: Pocket wetland, Berlin, Germany

Figure 36: Pocket wetland, Portland, Oregon, USA

Figure 37: Infiltration trench, supermarket car park, Scotland, UK)

II.6.1.3 Hopwood Park, M42 motorway service area, UK

The concept of the 'management train' has been used at Hopwood Park motorway service area (MSA) to provide BMP/SUDS techniques in series to improve the flow and quality of runoff in stages before discharge into the local watercourse.

Drainage water from a lorry park, the main access road, fuel filling area, coach and car parks are treated by the SUDS system. For the main access road, fuel filling area and coach park, a distinctive component is the two spillage basins which can isolate hazardous discharges (Figure 38). A constructed wetland treats 10 mm 'first flush' runoff (Figure 39) and a bypass swale collects stormwater overflow and conveys it to a balancing pond. 'The series of ponds, wetlands and low flow channels form a walk for visitors with information boards to explain the BMP/SUDS approach to managing rainfall on development sites.
www.ciria.org/suds/cs_hopwood_msa.htm

Figure 38: Spillage Basin, Hopwood Park, M42 motorway service area, UK

Figure 39: Constructed wetland, Hopwood Park, M42 motorway service area, UK

II.6.2 Urban green space BMPs

The following examples of BMPs/SUDS have not only contributed to the provision of green space in urban areas but have provided social, amenity and education benefits and opportunities as well as enhancing biodiversity. Rollo Mire, Scotland, illustrates a semi-natural wetland habitat near an urban area, which provides a model example in terms of design and management for systems in urban parkland or residential developments which incorporate BMPs as both functional and natural features. The water treatment areas of wetlands and pond BMPs should preferably be planted with local species with surrounding areas left unplanted in order to encourage colonisation by other local species. The other examples in this section show the introduction of BMP/SUDS and improved design to existing water bodies and drainage systems and the creation of BMP/SUDS systems in new residential developments.

II.6.2.1 Belo Horizonte, Brazil

As a demonstration site of the SWITCH project, constructed wetlands and detention basins will be retrofitted at the Zoo in Belo Horizonte city (Figure 40) and at Vilarinho (Figure 41) and their pollutant removal performance will be assessed together with an evaluation of the social acceptability of locating water quantity and quality management systems within recreational areas (SWITCH, 2007). The zoo wetland system will comprise pre-treatment followed by a planted wetland, maturation pond and final settlement pond. Rainfall, flow velocity and depth will be monitored at the inlet and outlet of each system to enable the hydraulic performance of each component to be quantified under various wet weather and dry weather conditions. Each system will be fitted with automatic water samplers at the inlet, mid-system and outlet to enable the continuous monitoring of wet weather events. Water quality during dry weather periods will also be assessed. The implementation of this monitoring programme will also enable the levels of diffuse pollution and contamination by wastewater and solid waste at a catchment scale to be assessed.

Figure 40: Scheme of the zoo wetland and sampling sites 1-4, Belo Horizonte, Brazil

Figure 41: Scheme of the Vilarinho wetland, Belo Horizonte, Brazil

The demonstration in Vilarinho combines a detention pond with flood control main purpose with a wetland, leading to pollution abatement, and equipment for sport activities. An on-going survey in this district will help to identify people's acceptance of this type of structure as well as to identify leisure and sports equipment that will meet the needs of the community.

The impact of a detention basin in relation to runoff and pollution abatement together with an evaluation of the public perception of risk in urban areas (health risk, flooding risk) as well as public perception and acceptance of detention facilities will be assessed in a project located within the Leitão creek catchment (surface area 350 ha) in which is located the Santa Lúcia detention basin (SLDB) (Figure 42). This detention basin began operating in 1953 with the main objective of controlling floods in the Belo Horizonte downtown area. However, as a result of the urbanisation of upstream areas in the 1970s, sediments, domestic sewage and solid waste heavily impacted on the SLDB. Formerly an in-line structure, in the 1990s the SLDB was restored as an off-line system and was also equipped with now very popular leisure facilities. There is already a good level of neighbourhood social organisation within this catchment, and this fact, together with the combined use of the SLDB, opens up interesting opportunities to investigate public participation on decisions related to urban water management.

Figure 42: River restoration, detention pond and green corridor, Belo Horizonte, Brazil

II.6.2.2 Sloterplas Lake, Amsterdam, the Netherlands

The water bodies in the Sloterbinnenpolder (SBP), a city lake of Amsterdam, have high nutrient loads (mainly phosphorus) which cause eutrophication problems, especially in the Sloterplas Lake (Figure 43). The sources of phosphorus loads to the Sloterplas Lake have been identified and both ecological and conventional engineering methods that could reduce phosphorus loading were assessed. The reduction of external phosphorus loads that could be achieved by surface runoff treatment and the treatment of water from neighbouring polders pumped into the SBP was quite high (75%), but was not sufficient to restore the lake due to the natural background loads, and the extensive internal load. However, with additional measures within the lake and its inlets such as the planting of reeds to create constructed wetlands, it seems that a good ecological condition of Sloterplas Lake could be achieved.

Figure 43: Sloterplas Lake, Amsterdam, Netherlands

II.6.2.3 Rollo Mire, Kintore, Aberdeenshire, Scotland, UK

In the UK, the Green Belt is an area of land on the outskirts of an urban environment which is protected from residential development. The management of wetland habitats within the green belt provides an opportunity to show the potential for BMP/SUDS wetlands to both enhance the landscape and provide habitat for wildlife. Rollo Mire is an example of a semi-natural wetland ecosystem which receives sustainable management by the Greenbelt group (Figure 44).
www.greenbeltgroup.co.uk

Figure 44: Rollo Mire, Kintore, Scotland, UK

II.6.2.4 Bourne Stream, south west England, UK

A series of five on-line lagoons of total area 1 hectare, were created in 2000 with funding from English Nature and planted with reeds in the Bourne stream catchment (Figures 45a and b). A shallow off-line wetland of total area 2500 m^2 was constructed a short distance upstream of the lagoon and provides initial treatment of first-flush surface runoff from the Ringwood Road, a major highway. The effluent from the wetland is then diverted to the lagoons for further treatment.

Figures: 45(a) and (b): Bourne stream, UK, pre and post lagoon construction

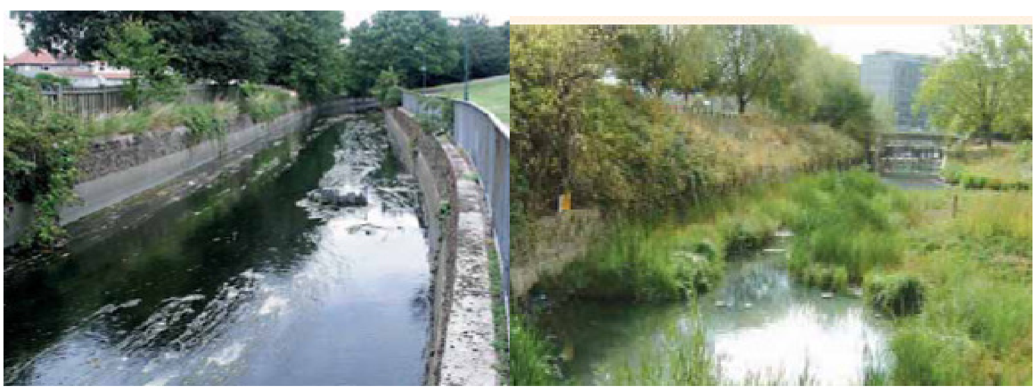
Following consultation with the local Community, a section of the Bourne Stream in Coy Pond Gardens, a public open space, was adapted from a concrete lined and straightened section by widening and lowering the banks and planting the area with suitable wetland species (Figures 46a and b). The section has developed as a water meadow providing an enhanced landscape feature and thus benefiting the local community by encouraging greater recreational use of the open space. Furthermore, water storage and flood attenuation have been improved and the vegetation and soft muddy banks provide a good habitat for wildlife.
www.bournestreampartnership.org/uk

(a) **(b)**

Figures 46: (a) and (b): Bourne Stream pools, UK, pre and post habitat creation

II.6.2.5 River Brent Park, north-west London, UK

Part of a degraded river channel in the River Brent has been restored in the first phase of a project from 1999-2003. The section was originally placed in U-shaped concrete channel and was prone to flash floods (Figure 47 a). It has been restored by restoring meanders to the straightened channel along its original route, creating a backwater channel and naturalising the river's banks. The planting of vegetation in the river bed and margins is a feature similar in design and function to swales and constructed wetlands (Figure 47 b). The soft-engineering features also provide flood protection and withstand erosion (Environment Agency, 2006).



(a) (b)

Figure 47: River Brent (a) 1999; (b) 2003

II.6.2.6 Welsh Harp Reservoir, north-west London, UK

The Welsh Harp Reservoir is a body of open water (96 ha) located in north-west London, which was constructed in the mid nineteenth century to provide water for two canals and to act as a flood alleviation basin (Figure 48). The area surrounding the reservoir was originally countryside but is now urbanised. The original open water has been reduced by the growth of, reedbeds, marshlands, willow carr woodland and grassland which provides habitats for resident and over-wintering waterfowl populations and the reservoir was designated a Site of Special Scientific Interest

(SSSI) in 1950. Floating rafts have been constructed in recent years to provide additional nesting sites and have attracted several pairs of the common Tern.

Figure 48: The Welsh Harp Reservoir, London.UK

II.6.2.7 Great Notley Garden Village, South East England, UK

Great Notley Garden Village (188 ha) is located near Braintree in south east England on former agricultural land and contains 2000 homes. Its design by Countryside Properties Plc includes a Country Park with an ornamental pond, wetland and surrounding woodland and grassland providing wildlife habitats and a central focus for community relaxation and recreation (Oldham, 1995). The constructed wetland (7900 m^2) and adjacent recreational pond (16,000 m^2) at the site have been designed to provide treatment and act as a balancing pond to store surface water runoff from the catchment and discharge it into the outfall system of ditches at a controlled rate (Figures 49 and 50).

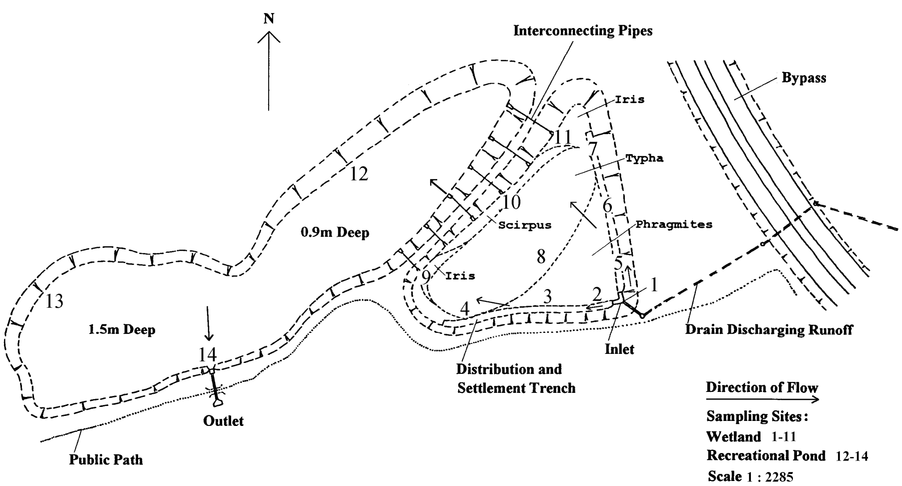


Figure 49: Constructed Wetland and recreational pond, Great Notley Village, south east England (Mungur et al., 1999).

The introduction of this constructed wetland adjacent to an ornamental pond in a substantial residential development enhances the landscape and provides a focal green space for the community.

Figure 50: Great Notley Village Constructed Wetland, UK

II.6.2.8 Lamb Drove, Cambridgeshire, UK

Lamb Drove is a new residential development of 35 affordable homes (built by a housing association) on a one hectare site, 15 km from the city of Cambridge. A range of BMP/SUDS measures were used including landscaped swales to treat surface runoff from roads and green space (Figure 51). The project was part of a European funded programme (FLOWS) and the project outcomes have been disseminated to a wide international audience (www.flows.nu). The lessons learnt from the project include the need to keep BMP/SUDS simple, not only to reduce maintenance costs but to increase the possibility of the systems being well maintained in the future. Surface-based systems such as swales enable problems to be identified and dealt with as they arise.

www.ciria.org/suds/cs_lamb_drove.htm

Figure 51: Swale, Lamb Drove, County of Cambridge, UK

II.6.2.9 Elvetham Hall, Fleet, Hampshire, UK

Elvetham Hall is a new residential development with a range of properties from flats to houses and is located next to a nature reserve in south east England. It has a landscaped pond to both retain and treat urban surface runoff and provide a central focus for the community (Figure 52) as well as providing an enhanced landscape feature with marketing benefits for the property developer and residents.

Figure 52: Stormwater receiving Pond, Elvetham,Hampshire, England, UK

II.7. Environmental Interpretation and Education

All BMP/SUDS can potentially offer opportunities for Environmental Interpretation and Education (Table 10). The use of signboards to explain their function is shown in Figures 31 and 32. This section presents examples of a BMP/SUDS system developed in a primary school, a system within a bird sanctuary with managed public access and a large constructed wetland system and Visitor Centre in Malaysia.

II.7.1 Putrajaya City, Malaysia

The Putrajaya wetland system, consisting of 24 constructed wetlands (200 ha) and a downstream lake (400 ha), is located in Putrajaya, the new Federal Government Administrative Centre in Malaysia (Figure 53). This innovative project has the advantage of developing a new city and associated stormwater management plan, without inheriting and needing to retrofit the infrastructure of an existing urban area. The city is committed to sustainable development and has allocated 70% of the land use as 'green space'. The wetland system enhances both the landscape and biodiversity of the area, with 70 plant species introduced for their aesthetic value or their ability to treat pollution. The wetlands have attracted many species of wildlife and a visitor centre and botanical park illustrate and explain their characteristics and ecological significance to the public.

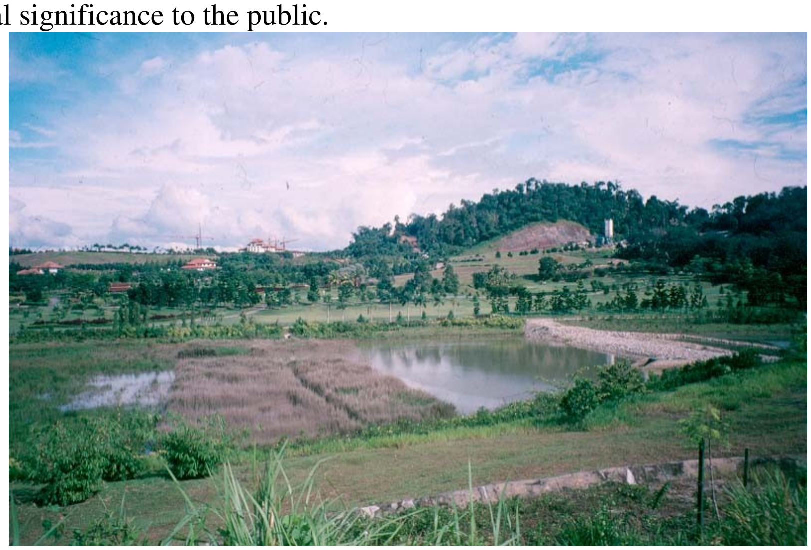


Figure 53: Constructed wetland cell, Putrajaya, Malaysia

II.7.2 Wetlands and Wildfowl Trust, Welney, UK

A new visitor centre for the Wildfowl and Wetlands Trust (WWT) bird sanctuary was designed around environmental and sustainable elements in keeping with the location and provides an area for visitors including a café, shop**,** educational facilities, exhibition and community space**.** Rainwater is collected from the building roof, combined with BMP/SUDS drainage in the car park allowing surface water run off from the site to be used to create ponds and a wetland habitat. Wastewater from the building is treated in a reed bed system to allow outfall into an adjacent water course (Figure 54);(Ove Arup, 2007).

Figure 54: Wetlands and Wildfowl Trust, Welney, UK

II.7.3 Matchborough First School, Redditch, Midlands, UK

This BMP/SUDS system contains swales which collect overland flows from an adjacent site and the runoff from the car park and playground, providing source control. The main driveway is drained to an extended detention basin. These systems connect to a constructed wetland, which also takes runoff directly from the roof and provides amenity as well as an educational resource (Figure 55). Risk is managed by appropriately designed education of the school children.
www.ciria.org/suds/cs_matchborough_school.htm

Figure 55: Constructed wetland, primary school, Redditch, UK

II.8. The role of BMPs in urban regeneration

The following examples illustrate the opportunities for introducing BMP/SUDS systems in brownfield urban regeneration projects. Green roofs are a suitable option as they do not require additional land take (Table 10). In contrast, constructed wetlands require a high land take but provide a focal point for community recreation as well as providing pollution control, flood attenuation and water storage.

II.8.1 Birmingham, UK

The city centre of Birmingham has been the focus for regeneration over the last 15 years, with the final quarter of Eastside being identified in 1999. Eastside covers 170 hectares of mixed development and contains many post-industrial sites similar to others found throughout the city centre which have remained derelict for 30 years or more. Regeneration in this area alone is expected to take more than 10 years and attract up to £3-6 billion investment (Figure 56). This process of regeneration has severely affected the habitats favoured by the black redstart bird in Birmingham City Centre. Inclusion of a city park and extensive green roofs as part of the architectural contribution to redevelopment seeks to reverse the decline in habitat quantity and quality and to contribute to the expansion of the black redstart population in Birmingham in accordance with the local biodiversity action plan, while simultaneously creating much needed habitat for other species (Figure 57).

Habitat creation and biodiversity enrichment provide an incentive for the demonstrations but extensive green roofs potentially provide much broader benefits and have an interesting, multifaceted role to play in the development of an integrated urban water management plan (SWITCH, 2007). They impact on storm water management, opportunities for urban water reuse and urban water quality as well as energy consumption and the general environmental quality of a city centre.

Figure 56: Plan of Eastside regeneration area, Birmingham, UK


Figure 57: Green Roof, Birmingham, UK

II.8.2 Helsinki, Finland

The city has a Master Plan to regenerate brownfield sites as residential areas with public and private partnerships and develop BMP/SUDS to the drainage systems. Public participation in the decision making process is a key feature of this process. An example of a water body which receives urban drainage is shown in Figure 58 (URGE, 2006).

Figure 58: Bay of Toolonlahti, Helsinki, Finland

II.9. Conclusion

There is considerable potential for BMPs/SUDS to play an important role in stormwater source control as well as reuse approaches for drinking water supply, irrigation, wastewater treatment, landscape and biodiversity enhancement, social and amenity purposes, and environmental education. Recent large scale developments in economically developed countries have adopted the latest greywater and rainwater water reuse technologies and systems for the irrigation of grass and green space. In contrast, in less economically developed countries there are many examples of the appropriate use of low cost BMPs for rainwater harvesting (such as water butts and jars). Most types of BMPs/SUDS have the potential to enhance the landscape and biodiversity of urban highways and green spaces and they can all offer opportunities for environmental interpretation and education.

References

American Society of Civil Engineers and UNESCO 1998. *Sustainability criteria for water resource systems.* Report of joint ASCE/UNESCO Task Committee on Sustainability Criteria. Project M-4.3. IHP IV. American Society of Civil Engineers, Reston, Va, USA.

Apostaki, S., Jefferies, C. and Souter, N. 2001. *Assessing the public perception of SUDS at two locations in Eastern Scotland.* 28-37 in Pratt,C.J., Davies, H.W. and Perry, J.L. (Edits): Proc. 1st National Conference on Sustainable Drainage. Coventry University, Coventry, UK.

Australian National Guidelines for Water Recycling: Managing Health and Environmental Risks, Phase 1 (2006). www.ephc.gov.au/ephc/water_recycling.html. Accessed 11 April 2007.

Bourne stream partnership (2006). www.bournestreampartnership.org/uk. Accessed 17 July 2008.

CIRIA. 2000. *Sustainable Urban Drainage Systems – design manual for Scotland and Northern Ireland*. CIRIA C521, CIRIA, London, 114p.

Centre for Alternative Technology (2006). Rainwater harvesting. Available: www.cat.org.uk/information/catinfo.tmpl?command=search&db=catinfo.db&eqSKUdatarq=20020925160005. Accessed 2 January 2007.

D'Arcy, B. and Chouli, E. 2007. *Europe's drainage gains - practical experiences of innovation in integrated urban infrastructure*. Water 21, 29-31.

Department of Trade and Industry, DTI (2006). Water recycling and reuse in Singapore and Australia. Global Watch Mission Report. DTI, London.

Dobbie & Partners Ltd. 1988. *North Weald Brook Investigation*. Report to Epping Forest District Council. C. H. Dobbie & Partners Ltd, Croydon, Surrey

Doyle, P., Hennelly, B. and McEntee, D. 2003. *SUDS in the Greater Dublin area*. National Hydrology Seminar, Dublin, 77-82.

Ellis, J.B., Shutes, R.B.E. and Revitt, D.M. 2003. *Constructed Wetlands and Links with Sustainable Drainage Systems*. R&D Tech. Report P2-159/TR1. Environment Agency for England and Wales. Bristol, UK. ISBN 1-8570-59182.

Ellis, J.B., Shutes, R.B.E. and Revitt, D.M.2003. *Guidance Manual for Constructed Wetlands.* R&D Tech. Report P2-159/TR2. Environment Agency for England and Wales. Bristol, UK . ISBN 1-844-321185.

Environment Agency (2006a). Rainwater reuse. Available: www.environment-agency.gov.uk/subjects/waterres/286587/286911/548861/861599/?version=1&lang=_e. Accessed 14 December 2006.

Environment Agency (2006b). Bringing your rivers back to life: a strategy for restoring rivers in North London. Environment Agency for England and Wales.

Fujita, S. 1997. *Measures to promote stormwater infiltration*. Wat. Sci. Tech. 36(8-9), 289-293.

Hall, M.J., Hockin, D.L. and Ellis, J.B. 1993. *Design of Flood Storage Reservoirs*. Report B014. CIRIA, London. ISBN 0-7506-1057-3.

Heal, K., Scholz, M., Willby, N. and Homer, B. 2007. *The Caw Burn SUDS: performance of a settlement pond/wetland SUDS retrofit.* In: Proceedings of 3rd National Conference on Sustainable Urban Drainage systems, Newman A. P., Pratt C. J., Davies J. W. and Blakeman J. M. (Eds.). Coventry University, Coventry, UK.

Hyder Consulting. 2004. *Retrofitting Sustainable Urban Drainage Systems*. Case Study-Dunfermline. Report No: NE02351/D1. Hyder Consulting.

International Water Management Institute, Ghana (IWMI), (2006). Information provided to SWITCH project.

International Water Year (2003). Water for our future - what are the trends? www.wateryear2003.org/en/ev.php-IRL_ID=3697&URL_DO=DO_TOPIC&URL_SECTION=201.html. Accessed 2 January 2007.

Jones, R.H. 1993. *Ecotoxicology of oil derived pollutants in urban receiving waters.* PhD thesis. Urban Pollution Research Centre, Middlesex University, London.

Lagerberg, I., Barraud, V., Shutes, R.B.E., Revitt, D.M. and Smith, A. 1998. *Treatment of Highway Runoff Using Constructed Wetlands: An Interim Manual*. Environment Agency for England and Wales, Thames Region, Reading Berks.

Marland, A. 1997. Case Studies. In: *Landscape Design and Urban Drainage*. Proceedings of a Seminar held at Heriot-Watt University, Edinburgh, UK, 18th-19th September 1997, 54-55.

McCann, B. (2007). Rain gains: the rise of rainwater harvesting. Water 21, February, pp13-14. International Water Association.

Mungur, A.S. 1997. *Performance Criteria for Evaluation of Urban Runoff Quality Impacts*. Unpublished PhD thesis. Middlesex University, London.

Mungur A.S., Shutes, R.B.E., Revitt, D.M , House, M.A. and Fallon, C. (1999) A constructed wetland for the treatment of urban runoff. In: M.H. Wong, J.W.C. Wong, and A.J.M. Baker (Eds) Remediation and Management of Degraded Lands, Ann Arbor Press, Michigan, USA, 329-341.

OveArup and partners(2007). Information provided by P.Sharp to SWITCH Workshop on Stormwater reuse. University of Birmingham, 8 January, 2007.

People and Planet (2003). Water use.
http://www.peopleandplanet.net/doc.php?id=593 Accessed 2 January 2007.

Scholes, L.N.L. (2007). Presentation to SWITCH Workshop on Stormwater reuse. University of Birmingham, 8 January, 2007.

Scholz, M. 2007. *Development of a practical best management practice decision support model for engineers and planners in Nordic countries*. Nordic Hydrology, doi: 10.21.66/nh.2007.001.

Seiker, H (2007). Presentation to SWITCH Workshop on Stormwater reuse. University of Birmingham, 8 January, 2007.

Shutes, R.B.E., 2001. Artificial Wetlands and Water Quality Improvement. Environment International, 26, (5-6), 441-447.

Shutes, R.B.E., Revitt, D.M., Scholes, L.N.L., Forshaw, M. and Winter, B. 2001. *An experimental constructed wetland system for the treatment of highway runoff in the UK*. Wat. Sci. Tech. 44 (11), 571-578.

Smet, J. (2003). WELL Fact sheet: domestic rainwater harvesting. www.lboro.ac.uk/well/resources/fact-sheets/fact-sheets-htm/drh.htm. Accessed 2 January 2007.

Sniffer. 2006. *Retrofiting Sustainable Urban Water Solutions*. Final Report Project UE3(05)UW5. Scotland and Northern Ireland Forum for Environmental Research.

Stovin, V.R. and Swan, A.D. 2003. *Application of a retrofit SUDS decision-support framework to a UK catchment.* Second National Conference on Sustainable Drainage, Coventry, UK, 23-24 June 2003, 171-180.

Swan, A.D. and Stovin, V.R. 2002. *A decision- support framework for the design of retrofit SUDS.* Int. Conference on Sewer Operation and Maintenance (SOM 2002). University of Bradford, UK.

SWITCH (2007). Demonstration project: Belo Horizonte.
(www.switchurbanwater.eu). Accessed 3 June 2008.

SWITCH (2007). Demonstration project: Birmingham. (www.switchurbanwater.eu) Accessed 3 June 2008.

SWITCH (2007). Demonstration project: Chongqing. (www.switchurbanwater.eu). Accessed 3 June 2008.

UKRHA (2006). Industry Fact Sheet 3. Enhanced capital allowance scheme as it applies to rainwater harvesting systems.
www.ukrha.org/download.php?file=press/03-EnhancedCapitalAllowances.pdf.
Accessed 2 January 2007.

URGE (2006). Making Greener Cities- A Practical Guide. EC URGE project- Development of Urban Green Spaces to improve the quality of life in cities and urban regions.

Villarreal, E.L, Semadeni-Davies, A and Bengtsson, L. 2004. *Inner city stormwater control using a combination of best management practices*. Ecol. Eng. 22, 279-298.

Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R. and Shaffer, P. 2007a. *The SUDS Manual: Updated Guidance on Technical Design and Construction*. Report C697. CIRIA, London. ISBN 0-86017-697-5.

Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R. and Shaffer, P. 2007b. *Site Handbook for the Control of SUDS*. Report C698. CIRIA, London. ISBN 0-86017-698-3.

Your home: Technical Manual (2005) Water use: rainwater.
http://www.greenhouse.gov.au/yourhome/technical/fs22.htm. Accessed 2 January 2007.