Stormwater as a Resource in the Urban Water Cycle: A Case Study in the SWITCH Demonstration City of Birmingham, UK.

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Abstract

The potential contributions of impermeable surface water discharges to urban water resource management strategies are considered through the development and analysis of an urban water cycle (UWC) study approach. The structure, outputs and benefits of a UWC study are described and a test application of the methodological approach is made to the Eastside development area within the SWITCH demonstration city of Birmingham, UK. Water demand and usage rates for the proposed 170ha regeneration area are quantified and potentially significant savings identified assuming re-use of stormwater runoff which would considerably facilitate a more sustainable future urban water cycle strategy.

Keywords: urban stormwater, urban water cycle (UWC) study, water demand and usage

1. Introduction

Urban water cycle (UWC) studies are intended to identify tensions between development proposals and environmental requirements as a means of addressing and facilitating potential solutions in an integrated, sustainable and cost-effective manner. The UWC approach primarily aims to confirm that the urban water cycle infrastructure can support developments identified within regional spatial planning strategies and local/municipal development frameworks. Water cycle planning represents a relatively new approach for urban drainage as a support for the provision of sustainable water cycle infrastructure for both new and existing urban areas, and adopts an integrated approach to total water cycle

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infrastructure provision. In this respect, the UWC approach provides a guidance framework for identifying the potential contributions that stormwater discharges can make to other components, and to the concerns of differing stakeholder groups, within the total urban water cycle. A water cycle study provides a strategy to deliver the most sustainable water services infrastructure at the right time and location to enable and optimise existing and future development. Such an approach not only requires effective stakeholder partnerships but also requires data sharing in terms of technical knowledge on the urban water resource cycle which embraces water supply, wastewater, surface water, flood risk and receiving waterbody quality and ecology. The collation and sharing of this mix of public, corporate and private information and data sources presents a considerable challenge for stakeholder partnerships concerned with urban water resource planning.

An urban water cycle (UWC) study can be regarded as being:

- a methodological approach for determining what water resource infrastructure is required, as well as where and when it will be needed,
- a risk-based approach ensuring that the planning process makes best use of available environmental capacity and is adapted to environmental, technical, costing and other major local/regional constraints
- a structural framework for stakeholder engagement and collaboration,
- a process procedure whereby diverse and disparate knowledge and information is brought together to make better and more integrated risk-based decisions on the urban water environment,
- a basis for developing stormwater management plans (SWMPs) and preliminary strategic (flood and pollution) risk assessments (SRAs) as well as ensuring compliance with other regulatory requirements such as mandated under the EU Water Framework Directive (WFD) and with local/regional development planning policies and regulations.

An effective UWC study acts as a vital evidence base for local/regional development plans, showing how water services and the water environment have been considered in the strategic planning process. As such it can facilitate a water-based comparative assessment of development option designs and locations and can feed into and underpin core planning and regulatory control strategies. This paper describes and applies the formal structure of a UWC study approach to a proposed 170ha development area within the SWITCH demonstration city of Birmingham, UK to illustrate the potential contributions that stormwater runoff can make to future sustainable urban water resource management. Full detail of the UWC methodology and of the test application in the Birmingham pilot study is given in Ellis and Revitt (2010a).

2. An Urban Water Cycle (UWC) Study

2.1 Carrying out an Urban Water Cycle (UWC) Study

A UWC study normally covers two survey stages comprising outline and detailed studies followed by an implementation and review stage (Figure 1). The lower Level 1 risk assessment study should provide a strategic scoping of the nature and extent of major flood and pollution potential (particularly for zones of high risk likelihood), and their implications for any local development plans. The main purpose and thrust of the upper Level 2 risk assessment would be to address the identification, quantification and mitigation of uncertainties associated with the flood and pollution risks in zones/areas carrying average to minimum risks as judged by the lower Level 1 analysis. However, it may not be necessary to undertake all three stages as sufficient preliminary risk assessment and other supporting planning evidence, provided perhaps from a stormwater management plan (SWMP), may already be available to proceed directly to a detailed Level 2 UWC study, and the timing of the various stages may need to be altered to fit in with local circumstances. The UWC approach is context rather than system-oriented and is an adaptive rather than optimisation approach, with the emphasis being on process, uncertainties and identification of a range of potential mitigating solutions. A major part of both outline and detailed Level 1/2 studies are concerned with the identification, collation and sharing of relevant data and information, which may be a source of stakeholder tension where sensitive commercial data is involved (Fletcher and Deletic; 2007; Ellis and Revitt, 2010b). It is also important that stakeholders recognise the various constraints that may apply to the identification of technically feasible solutions and accept “trade-offs” between competing or conflicting objectives.

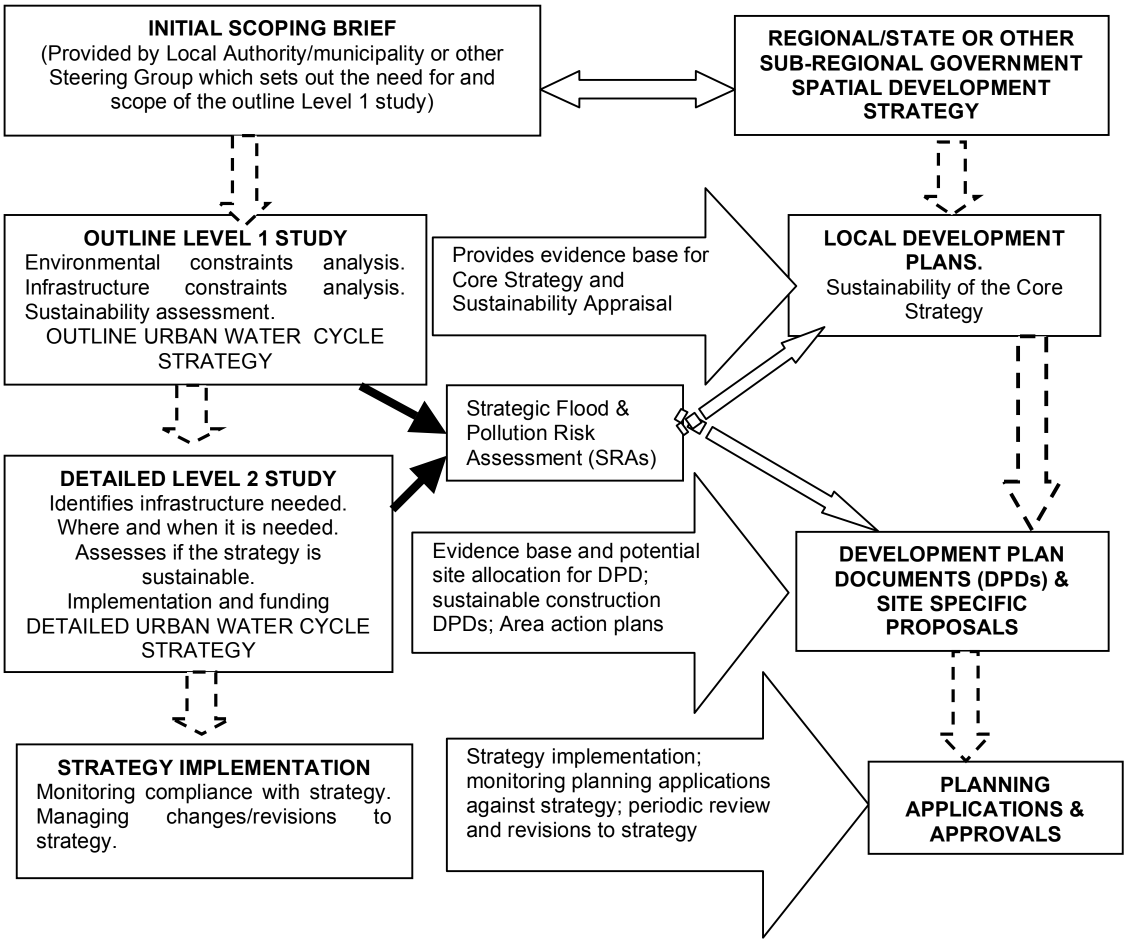

Figure 1. Stages in an Urban Water Cycle (UWC) Study.

2.2 A Working Brief for an Urban Water Cycle Study

A water cycle strategy requires a partnership process to integrate urban development and associated regeneration within the context of identified water resource and related environmental constraints and future water services infrastructure planning as a basis for achieving a more sustainable urban development outcome. An urban water cycle study therefore should produce a coordinated approach to strategic spatial plan-making by holistically addressing the issues of water supply, water quality, wastewater collection and disposal and flood risks in both the built-up area and receiving waterbodies, and at the same time ensuring that infrastructure is provided in a timely manner. It is within this general UWC framework that a template for the provision and operation of surface water drainage infrastructure should be considered. It is therefore difficult to isolate and independently consider surface water management from other water components of the urban water cycle when developing a catchment level water cycle strategy,

The brief for a water cycle study strategy study should contain the following elements:

- the background and context to the reasons why a water cycle strategy is required together with the prevailing legal and planning framework.
- the scope of the strategy and the key outputs and deliverables required of the water cycle strategy study.
- suggested information and data sources as well as skills required to undertake the UWC study should be stated. Lead and key partners to the study should also be identified together with any project steering review group.
- any particular issues that the UWC needs to address in more detail in terms of further study, analysis and consultation. This will comprise the core of the Outline Level I Initial Scoping Study as identified in Figure 1.
- a summary and recommendations of the inputs necessary to progress the water cycle study strategy to the detailed Level II study.

2.3 UWC Outputs and Benefits

The outputs from the outline Phase 1 UWC study should be reports that address the following questions:

- what and where are the risks from surface water flooding for development proposals and will these developments be resilient to the effects of future climate change and the likely impacts on flood risk drainage and water supply?
- how will the effects of staged “parcel” development impact on the provision of an integrated, sustainable drainage infrastructure?
- how can rainfall-runoff and associated overland flows be managed within the development area for extreme storm events and what is the potential for source control BMP/SUDS implementation?
- are there locations that can be safely utilised for attenuation, infiltration and/or storage of exceedance flows?
- what water savings and demand management approaches can be implemented within the developments, especially in respect of potential rainwater contributions to other components of the urban water cycle?
- is there an increased risk of stormwater outfalls and overflows operating outside their agreed limits as a result of the proposed developments?
- will there be a water quality impact on the receiving watercourses and/or groundwater resources?

- how will other outstanding concerns and uncertainties in respect of urban surface water drainage infrastructure be addressed e.g costs, adoption, maintenance etc.? The scoping study might identify options for first-cost estimates for water cycle infrastructure as well as possible alternative cost apportionment mechanisms.
- identify any information, data, funding or policy/planning gaps and technical uncertainties that require further exploration in a more detailed Phase 2 UCW study in conjunction with the local development planning process.
- identify procedures and supporting structures to ensure a coordinated stakeholder approach to strategic water resource management.

The outline Phase 1 UWC study should therefore provide an evidence-based study which specifically addresses the impact of developments on the water cycle, with particular emphasis on the consequences for the provision and maintenance of surface water drainage infrastructure and management. The output should provide an important component of the local authority/municipal development plans and should build on strategic flood risk assessments (SFRAs) and any existing supplementary planning guidance on drainage as indicated in Figure 1. In addition, the UWC material should provide a significant evidential document to local SWMPs and wider catchment-level planning policy and strategy.

3 Stormwater Within a UWC Study for Birmingham Eastside

3. Background and Context of Birmingham Eastside

The Eastside development area represents a major urban regeneration initiative within Birmingham city centre and covers an area of 170 hectares (www.sustainable-eastside.net). The intensity of the built-up area means that there is a high impermeable surface cover which generates large volumes of surface water runoff having very short times of concentration. The outcome of this is that the receiving River Rae channel as well as the local highway network, has been subject to severe overland flow flooding incidents in the historic past. However, this high impervious cover, combined with steep slopes and the low hydraulic capacities of the small diameter surface water sewers (usually less than 160mm), mean that large volumes of overland flow are generated during wet weather conditions leading to intense, localised pluvial flooding over the urban surface. Surcharging of the separate sewers in the development area is known to occur with storms exceeding the 1:5 Return Interval (RI) event (Groundwork Birmingham & Solihull, 2007).

The Eastside initiative intends to promote a new city quarter based on the themes of learning, technology and industrial heritage creating up to 12,000 new jobs during the lifetime of the initiative (www.birmingham.gov.uk/eastside). In addition, it will accommodate 3500 new dwellings as well as a range of business premises, a 3.2 ha city park and other public open spaces; detail of the proposed allocation of urban activities within the development area is given in Figure 2. This figure illustrates that highly impermeable landuse types such as commercial, office, education and retail activities dominate the development profile. Whilst such building types can present a highly impermeable coverage, they also offer considerable potential for green roofs, roof disconnection and associated infiltration systems as well as stormwater/greywater recycling schemes. The discrete nature of the separate development parcels within the planned regeneration area (see Table 2 for detail), and their staged delivery, mitigates against an integrated, holistic drainage infrastructure planning approach

(Ellis *et al*., 2010). However, it is governance mechanisms in the planning process which comprise the major barrier at the local municipal level to the achievement of strategic integrated implementation of drainage infrastructure (Ellis and Revitt, 2010b), rather than any inherent technical difficulties.

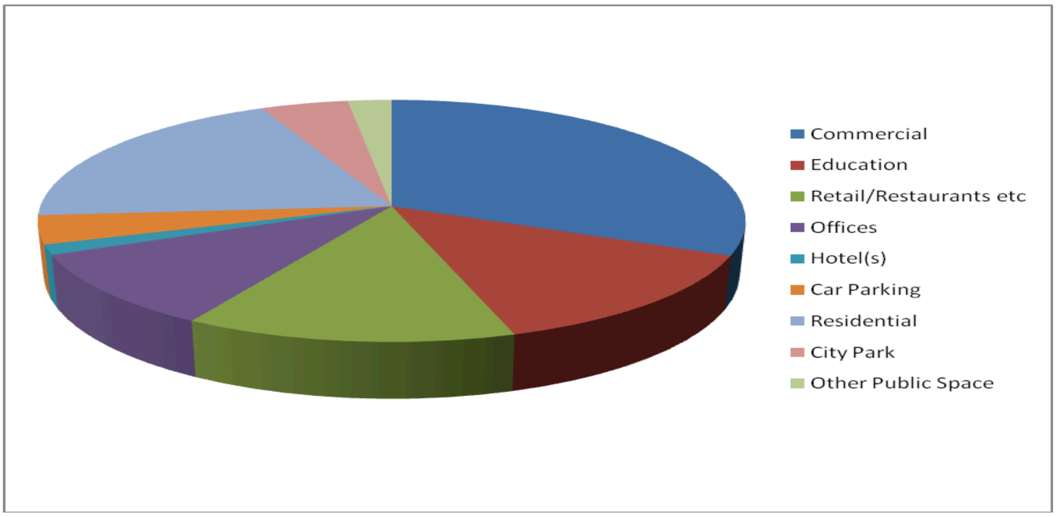

Figure 2. Proposed Landuse Activities for Birmingham Eastside

3.2 Main Stormwater Concerns of and Constraints to the Eastside UWC Study

Outline planning permission has been granted for the various mixed landuse development parcels of Birmingham Eastside and initial site clearance phases of the development have already taken place. The £2.7 B investment in this urban regeneration programme is being driven by Birmingham City Council who have prime responsibility for local highway and surface water drainage. Severn Trent Water holds prime responsibility for wastewater collection and conveyance, with additional core responsibilities for aspects of surface water drainage. The Environment Agency (EA) currently have responsibility for the regulation of surface water drainage in respect of pluvial overland flooding, although this responsibility and associated duties is intended to pass to the local authority on passage of the forthcoming UK government Floods & Water Management Bill (Defra, 2009). The EA also hold full responsibilities for receiving water quality in respect of both surface and groundwaters.

The primary concerns for surface water drainage infrastructure provision across Eastside include:

- water demand and usage rates and the capacity to meet requirements
- the need for on-site attenuation, storage and/or infiltration facilities especially in respect of overland flows associated with extreme storm events
- the need to maintain and/or extend the drainage infrastructure, including retrofitting, where appropriate
- the timetable for staged and integrated planning and delivery of drainage infrastructure controls
- the operational reliability and sustainability of the drainage network resources being delivered.

Table 1. Development Constraint Matrix

Water Resources		Wastewater		Surface Water Drainage and Pluvial Flood Risk	Fluvial Flood Risk		
Water Resource Availability	**Water Supply Network**	**Sewer Network**	**Sewage Treatment Works (STW)**		**FZ1**	**FZ2**	**FZ3**
Water resource available to meet planned developments	Existing network available with spare capacity	Existing sewer network can accommodate the proposed developments	Existing STW flow headroom can accommodate the proposed developments and there are no compliance issues	Low risk of flooding within sites or downstream	Flood Zone 1; Low probability of annual exceedance (<0.1%; <1:100)		
Water resource available but may need new source(s) to meet developments	Existing network available with no spare capacity	Existing sewer network may need to be upgraded	Existing STW flow headroom can accommodate the proposed developments but there are compliance issues	Medium risk of flooding within sites or downstream	Flood Zone 2; Medium probability of annual exceedance (1% - 0.1%; 1:100 – 1:1000)		
Exisrting resources not adequate to meet developments	No existing sewer network available to serve the specific development parcel(s)	Existing sewer network cannot accommodate the proposed developments	Existing STW flow headroom cannot accommodate the proposed developments	High risk of flooding on development site(s) or downstream	Flood Zone 3; High probability of annual esceedance (>1%; >1:1000)		

Stage 1 of the UWC study would essentially be a desktop study exercise drawing on existing technical work and strategic planning documentation provided by the local authorities and their statutory partners, identifying the constraints to and opportunities for future development growth. In addition, the desktop study would take cognisance of strategic regional and national guidelines for drainage infrastructure controls and management. The Stage 1 outline scoping study might consider alternative strategic options within the context of the identified constraints as illustrated in the colour-coded Table 1 matrix. This matrix approach enables the identification of relative degrees of difficulty and constraints in providing adequate water related services and infrastructure to the development area.

This initial Stage 1 scoping study will include the collation and analysis of available data, consideration of baseline conditions, identification of stakeholder partners and potential strategic options as well as guidance on areas/aspects for further consideration in Phase 2 to inform decisions on particular development parcels. Building on the outcomes and findings of the Stage 1 study, a more detailed Stage 2 strategic analysis should involve further technical studies of specific issues and uncertainties in conjunction with the local development planning process to ensure integrated and timely delivery and management of water services and associated infrastructure to provide more efficient and sustainable future approaches.

3.3 Water Demand and Usage in Birmingham Eastside

A first-order inventory and benchmarking of stormwater and wastewater generation within the Eastside development area has been undertaken by Coyne *et al.*, (2008) which can be used as a baseline input for the Level I scoping stage. This analysis was based on a 1:2 year return interval (RI) storm event, for which an effective runoff rate (with instantaneous peak discharge) of 26.4 mm/hour was derived by reference to local rainfall records. However, it should be noted that a 5mm rainfall event in April 2000 produced a peak intensity of 113 mm/hour, although the storm only occurred over a relatively short period of time. Thus a five-fold reduction in the intensity has been applied in the modelling analysis by Coyne *et al* (2008). The modelling assumes that this storm design threshold meets the Environment Agency regulatory requirements that no surface flooding equivalent to the 1:30 RI storm event should result from the predicted outflows. The analysis also assumed a 0.9 runoff coefficient for all the development parcels, with the exception of the Green Park development parcel for which a value of 0.4 was assigned. Maximum flows in the combined sewer system (with peak sewer flow rates limited to 2 m/s) were assumed to arrive simultaneously at sewer node points and a climate change addition of 20% - 30%, as well as an 80% limitation to runoff from each development parcel, were applied to the analysis. These requirements serve to add to the amount of local attenuation (and/or storage) that would be necessary for outflows generated at each site.

Table 2 shows the peak water usage rates for each of the development parcels together with their predicted peak wastewater flows for the modelled 1:2 storm event. Table 3 shows the predicted peak flows at various nodal points in the surface water sewer network and the likelihood of surcharging for the same storm event. A separate modelling analysis for a pilot 4.5 ha sub-catchment of the Eastside development area has been undertaken for a low frequency, high magnitude (<1:80 RI) storm event which occurred on 13/14 June 2007 (Viavattene *et al*., 2010). This event generated a total of 35 mm rainfall over a 10 hour period with a maximum intensity of 36 mm/hour and produced a peak outflow of 568 m^3/hour for the surface water system. The small diameter sewer network in this sub-catchment has a maximum hydraulic capacity of 0.2 m^3/s which is considerably less than indicated for the sewer network shown in Table 3. The tabled data is based on information supplied by the developers who may well be overestimating some of the pipe capacities for individual sites. Irrespective of these reservations and the working assumptions of both modelling approaches, it is evident that pluvial surface flooding can be expected for storm events exceeding the 1:30 RI.

Table 2. Summary of Peak Flow Data for Eastside Water Services.

Development Parcel	Contributing Area (m^2)	Peak (Average) Water Demand (l/s)	Peak Wastewater Discharge (l/s)
1 City Park	42900	22.0	50
2 Curzon Park	40470	32.5 (5.8)	314
3 Curzon Gateway	16200	6.0 (2.1)	120
4 VTP200			
5 BCU	14164		105
6 Ventureast	52609	58.0 (4.5)	401
7 Masshouse	62483	(3.8)	462
8 Martineau Galleries	54997	(2.5)	407
9 City Park Gate	18939	(6.2)	140
10 Millenium Point	48562	1.4	360
11 Multi-storey Carpark	8462	Negligble	63
12 Warwick Bar	18600	10.0 (1.0)	104
13 Devonshire House			
14 Typhoo Wharf	37400	(1.1)	277
15 UB40	3965	(0.5)	29
16 Aston Science Park	89030	(3.0)	659
17 Aston University	254450	(3.5)	
TOTAL	**77 (ha)**	**~106**	**3491**

[After: Coyne *et al*., 2008]

Table 3. Peak Flows in the Eastside Surface Water Sewer System

Sewer Node	Contributing Parcel(s)	Pipe Capacity		Total Peak Flow in Pipe (m^3/σ)	Surcharge Potential
		Minimum (m^3/s)	Maximum (m^3/s)		
A	1,4,6,11	0.9	1.8	0.5	Unlikely
B	1,2,4,5,7,8,9,10,11	0.9	1.7	2.3	Probable
C	1 - 12, 14, 15	5.1	5.1	2.8	Unlikely
D	4,11	0.1	0.1	0.06	Unlikely
E	1,4 - 11	0.9	1.7	1.9	Probable
F	6	0.6	0.6	0.4	Unlikely
G	7	0.1	0.1	0.5	Probable
H	8	0.6	0.6	0.4	Unlikely
I	8,9	0.4	0.4	0.5	Probable
J	1,4,6,10,11	0.9	1.8	0.8	Unlikely
K	11	0.1	0.1	0.1	Unlikely
L	1,2,4 – 12,14,15	8.3	8.3	2.7	Unlikely
M	13	0.08	0.07	0.04	-
N	14	0.1	0.1	0.3	Probable
O	1,2, 4 - 11, 15	0.9	1.7	2.3	Probable
P		0.9	1.8	0.7	Unlikely

[After: Coyne *et al*, 2008]

4. Stormwater Contributions to the Urban Water Cycle in Birmingham Eastside

The two modelling approaches described above imply that anything between 7560 – 58680 m^3 of instantaneous temporary attenuation storage would be required assuming that all impermeable surface runoff (but excluding highway drainage) occurs to the separate sewers. Based on the national guidance contained in the UK government strategy document for future water usage (Defra, 2008), it could be expected that at least a 20% reduction on these estimated discharges might be achieved through water efficient fittings to WC, washbasin and dishwashers, which would reduce overall water demand to about 80 l/hd/day. This is a very low daily consumption rate and may well be overly optimistic given the lack of "take-up" in water efficiency appliances within current (and approved) development proposals. However, substantial reductions in storage requirements in the order of 10% - 20%, could be achieved through the introduction of green roofs and limited source infiltration controls, both of which could be readily included into the drainage design of the retail/commercial premises which feature prominently in the regeneration proposals..

The introduction of recycled "greywater" facilities could undoubtedly lead to further substantial reductions in the combined sewer discharges to treatment as reported in Table 4, which would be in the order of 35% - 40% according to the household consumption data reported by Defra (2008). One estimation for a 1.1 ha development parcel of residential/apartment roofing suggested that water savings of 8,700 m^3/year could be achieved through rainwater harvesting with a payback time of 3 years (Faber Maunsell, 2004). The same study also claimed a 18.6 m^3/year "greywater" recycling capacity for a 350 bed hotel planned for another development parcel and having a 10.5 year payback time.

Table 4 indicates the potential for the implementation of rainwater harvesting and greywater recycling schemes within Birmingham Eastside together with estimated payback times (excluding lifecycle costs). However, such recycling schemes would appear prohibitive given the high "upfront" implementation and "follow-on" maintenance costs, as well as the possible requirement for the implementation of a third "labelled" supply system. These considerations mean that it is highly unlikely that greywater recycling will be introduced into the Eastside developments even for non-potable uses. Nevertheless, irrespective of these reservations, it is acknowledged by Defra (2008) that the introduction of rainwater harvesting schemes to impermeable roof surfaces could meet a significant proportion of on-site garden/lawn watering requirements which might reduce total water demand by 5% - 10%.

Table 4. Stormwater and Greywater Re-Use in Birmingham Eastside.

LANDUSE SECTOR	RAINWATER HARVESTING		GREYWATER RECYCLING	
	Potential	Payback Time (Years)	Potential	Payback Time (Years)
Single residential	✓	16	✓	44
Shared residential	✓✓	3.1	XX	-
Public community buildings	✓	6.9	XX	-
Hotels	✓	38.4	✓	10.5
Commercial office buildings	✓	?	XX	-
Retail buildings	See Mixed use development			
Industrial buildings	✓	?	?	?
Leisure buildings	✓	6.1	✓	7.8
Public open space	✓✓	?	XX	-
Mixed use developments	✓✓	?	✓✓	4.1

KEY: ✓ Potential; ✓✓ High potential; XX Negligible potential

[After: Faber Maunsell, 2004]

5. Conclusions

Although the above brief demand/usage analysis of the UWC study incorporates substantial uncertainties and data limitations, it is clear that there are opportunities for future re-distribution of water resources in the Birmingham Eastside developments. Within future water resource re-allocations, it is also evident that stormwater contributions could be significant in facilitating a more sustainable urban water cycle strategy. Management of surface water flows during extreme events within the development area will undoubtedly require the introduction of further attenuation/storage controls which could be used as a (re)source to meet demands elsewhere in the urban water cycle, including on-site amenity lakes/fountains, lawn/garden irrigation, groundwater recharge etc., in addition to emergency supplies for fire-fighting purposes. The realisation of such surface water redistributions to other components of the urban water cycle is largely dependent on both the political will of the city planning authorities and on developer motivation. There is no clear indication at the present time that the Eastside regeneration will exploit stormwater as a future resource, but forthcoming UK planning legislation and environmental regulation in relation to urban pluvial flood risks and diffuse pollution may become a driver in the reconsideration of existing thinking on this issue.

References

Coyne, R.,Last, E., Mackay, R and Sharp, P. 2008. *Birmingham Eastside Utilities Report*, SWITCH Learning Alliance report. www.switchurbanwater.eu.

Defra. 2008. *Future Water: The Government's Water Strategy For England.* February 2005. Cm 7319. Dept. Environment, Food & Rural Affairs. HMSO. London. UK.

Defra. 2009. *Draft Flood and Water Management Bill*. House of Commons, Environment, Food & Rural Affairs Committee (EFRA). HC 551-1. HMSO, London. UK

Ellis, J.B and Revitt, D.M. 2010a. *Stormwater as a Valuable Resource Within the Urban Water Cycle*. SWITCH Deliverable 2.2.4a. July 2010. www.switchurbanwater.eu

Ellis, J.B and Revitt, D.M. 2010b. The management of urban surface water drainage in England and Wales. *Water & Environ. Journ.*, 24, 1 – 8.

Faber Maunsell. 2004. *Greywater Recycling and Rainwater Harvesting at Birmingham Eastside*. February 2004. Groundwork Birmingham & Solihull. Birmingham, UK.

Fletcher,T and Deletic, A. 2007. *Data Requirements for Integrated Urban Water Management*. Urban Water Series, UNESCO-IHP, Paris and Taylor & Francis (Routledge Group), London, UK.

Groundwork Birmingham & Solihull. 2007. *Green Roofs for Eastside*. Report January 2007. Hyder Consulting, Birmingham. UK.

Viavattene, C., Ellis, J.B., Revitt, D.M., Seiker, H and Peters, C. 2010. The application of a GIS-based BMP selection tool for the evaluation of hydrologic performance and storm flow reduction. *Proc. 7th Int.Conf. Sustainable Techniques and Strategies for Urban Water Management; NOVATECH10*. 28 June – 1 July 2010. GRAIE, Insa de Lyon. Lyon, France.