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Scenario-based sustainable water management and urban regeneration

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Deployable output (source availability) from water resources in north west England is predicted to decrease over the next 25 years. Alternative supply management strategies are planned to help avoid a deficit in the supply–demand balance within the region but have yet to be considered in detail. This paper assesses the contribution of such an alternative supply strategy at local level on the water resource supply–demand balance at regional level based on a proposed urban regeneration site in north west England. Various water conservation and reuse measures are investigated considering local and regional conditions and constraints. Four future scenarios are presented and used to describe how the future might be (rather than how it will be), to allow an assessment to be made of how current 'sustainable solutions' might cope whatever the future holds. The analysis determines the solution contributions under each future and indicates that some strategies will deliver their full intended benefits under scenarios least expected but most needed. It is recommended that to help reduce the regional supply–demand deficit and maximise system resilience to future change, a wide range of water demand management measures should be incorporated on this and other sites.

1. Introduction

The effective and efficient use of water is widely acknowledged as an important facet of the delivery of sustainable urban regeneration (EA, 2003). This is supported by a whole raft of legislation and regulation both in the planning domain (e.g. planning policy statement 25 (CLG, 2010a), the sustainable communities plan (ODPM, 2003), the code for sustainable homes (CLG, 2010b)) and in the water domain (e.g. the Water Framework Directive (EC Environment, 2000), future water (Defra, 2008), water cycle studies (EA, 2009a), the Flood and Water Management Act 2010 (Defra, 2010)). The impact of the coalition government's localism agenda and resulting lack of regional perspective can be added to the complex mix!

The work reported in this paper explores how, within this complex regulatory setting and using an urban regeneration site as an example, alternative strategies for the management of water demand at local level can be assessed as a contribution to a predicted future water resource deficit in the region. The aim is to consider the overall water cycle, determine the scope for water minimisation, conservation and recycling and to generate a set of sustainable water management strategies with maximum resilience. This approach facilitates transition from linear urban water management practice (in which water is imported, processed and exported as waste by conveying wastewater and stormwater away from urban setting) to more cyclic water management, with reduced import of water, high rates of recycling and reduced wastewater and stormwater (Butler *et al.*, 2011).

In what follows, the planning guidance for the site will be reviewed for sustainable water management options considered by the developers. Policies related to water management in urban development will be presented. Also strategic asset management and water resources management plans reports, prepared by the relevant water service provider, will be analysed to identify the main constraints for the development. The resilience of the proposed sustainable water management options will be discussed. Finally, the supply and demand management options will be compared, considering local conditions and constraints, in terms of water savings/yield and benefits as well as their resilience to a range of changes in the future using the urban futures methodology as outlined in Rogers *et al.* (2012).

2. Background

2.1 Development and planning framework

The proposed urban regeneration site (Luneside East site) is located within Lancaster city and covers a total of 6·6 ha. The proposal for the area, set out at the outline planning phase, includes approximately 350 homes and 8000 m^2 of commercial buildings. A number of studies have been undertaken to characterise, quantify and assess the wide range of constraints pertaining to the development. In the planning guidance documents, the water-related issues are summarised as follows (LCC, 2004, 2007).

- Land contamination: studies have identified extensive and severe existing problems of land contamination across the whole of the Luneside East site area to the west of the main railway line, which require remediation work. Contaminants in the soil and groundwater pose a risk of pollution to controlled waters and potentially to the fabric of buildings and infrastructure.
- Mitigating flood risk: the site adjoins the river Lune and there is flood risk associated with the site. The council will require appropriate measures to protect the whole Luneside East site area from unacceptable flood risk by means of the implementation of appropriate measures of flood defence, attenuation and mitigation. Even though flood risk has been reduced by development of 1:500 year standard flood defence, the following measures have been considered as an additional flood protection guide to developers.

- No buildings should be constructed within 8 m of the river wall. It is currently proposed to raise ground levels by some 500 mm and set dwelling floor levels at a minimum of 200–300 mm above this. Depending on global warming predictions, higher ground levels may need to be considered for the development and its flood defences.
- It should be ensured that surface water drainage is carried, when practicable, by means of sustainable drainage systems (SuDS).
- In case of a significant increase in flood risk off-site, it may be necessary to include some form of compensation storage within/outside the development (e.g. lowering levels in some parts of the site and designating these for amenity use).

- Water conservation: efficient use of water (including greywater recycling) and the increasing use of demand management and new technologies to reduce energy and water consumption are mentioned as possible options.
- Infrastructure: United Utilities Water plc has indicated that a separate metered water supply will be required at the developers expense. Also the site must be drained on a separate system with only wastewater connected to the foul sewer. The sewerage system has sufficient hydraulic capacity to accommodate drainage from the new development, without leading to any significant increase in the frequency or duration of operation of combined sewer overflows.

2.2 Water resources and water supply

The case study site is within United Utilities water supply area (United Utilities, 2009). The company provides water and wastewater services to 2·9 million homes and a population approaching seven million across the region. The company supplies 2000 Ml of water and treats 1271 Ml of wastewater every day. Water is supplied to four discrete water resource zones, one of which is the integrated resource zone that covers the Luneside case study area and serves 95% of the region's population.

In 2006/2007, the average per capita consumption rates were 139 and 149 l/day for normal weather and dry weather, respectively. The average per capita consumption rate forecast for 2034/2035 is 129 l/day for normal weather, which is consistent with the government's future water (Defra, 2008) ambition of achieving 130 l/day by 2030. For dry weather, it is predicted that per capita consumption will reduce by only 4 litres from 149 to 145 l/day. However, it is expected to achieve even lower levels if compulsory metering becomes a statutory requirement. Growth in customer metering in north west England shows a reduction in water use by 8·3%. It is predicted that household meter penetration will increase to 60% by 2035 from 21% in 2006/2007. It is estimated that a water demand reduction of 10 Ml/day in a dry year by 2014/2015 (increasing to 22 Ml/day by 2034/2035) can be achieved by household customers who opt to use water meters. The water company is aiming to achieve the mandatory water efficiency targets introduced by OFWAT in 2008 of 2·95 Ml/day each year, 9 Ml/day by 2014/2015, increasing later on to 12 Ml/day through a base service water efficiency programme (saving 1 litre of water per property per day on average through water efficiency activity). A programme of economic water efficiency measures requires water companies to consider additional water efficiency activity, above the base level, to save 4 Ml/day by 2034/2035.

In 2007/2008 the water available for use for the integrated zone was approximately 1900 Ml/day. The company estimates that by 2012 a bidirectional pipeline from Prescot Reservoir in Merseyside to Woodgate Hill Reservoir in Bury will increase the water available for use in the integrated zone by 16·6 Ml/day (United Utilities, 2011). The impacts of sustainability reductions (due to abstraction licence changes) from 2014/2015 and climate

	2006/2007	2009/2010	2014/2015	2019/2020	2024/2025	2034/2035
Baseline deployable output	2147·5	2119·7	2119·7	2119·7	2119·7	2119·7
Benefit of west-to-east link from 2012/2013			16·6	16·6	16·6	16·6
Sustainability reductions impact from 2014/2015			−32·9	−32·9	−32·9	−32·9
Climate change impact		−3·4	−11·9		−23·4	−28·1
Forecast deployable output	2147·5	2116·3	2091·5		2080·0	2075·3
Water available for use	1931·7	1904·6	1879·8	1871·3	1868·4	1863·6
Dry weather demand	1873·8	1809·3	1773·0	1767·5	1770·5	1808·7
Target headroom	41·4	53·4	79·3	99·0	106·0	129·5
Supply–demand balance	16·6	42·0	27·5	4·8	−8·0	−74·6

Table 1. Supply–demand balance 2006/2007 to 2034/2035 (Ml/day) for integrated water resource zone (United Utilities, 2009)

change in 2034/2035 are estimated at −32·9 and −28·1 Ml/day, respectively, for the integrated zone. The target headroom for the integrated resource zone was 41·4 Ml/day in 2006/2007 and is expected to increase to 129·5 Ml/day in 2034/2035. These values have been considered to safeguard customers and the environment against uncertainties (political, social, environmental and climate change and technical factors) associated with forecasting water supply availability and water demand. Table 1 shows that the scale of deficit driven by sustainability reductions and climate change cannot be met by operation of the bidirectional pipeline alone, and despite additional allowance for unforeseen conditions there will be some imbalance in supply and demand towards the end of the water planning period (2034/2035).

In Table 1, dry weather demand represents metered and unmetered household consumption, non-household consumption, other water uses and leakage. Except household demand all the other demands are expected to reduce by the end of the planning period.

Table 2 summarises the anticipated changes in population and household water demand based on the water company projection. In this work, the dry year demand is considered for analysis as it represents higher demand than a normal year demand (i.e. more extreme condition) when water availability in water resources is lower.

United Utilities has explored a number of demand and supply water management strategies as possible options to maintain adequate future supply and demand. Among the demand management strategies the following have been considered.

- Leakage reduction through mains replacement; enhanced detection and repair or pressure reduction can save 8 Ml/day by 2024/2025 and 22·8 Ml/day by 2034/2035.
- Water efficiency measures such as offering free showerheads, free household water audits, subsidised water butts or retrofitting rainwater harvesting systems can save 4·1 Ml/day by 2034/2035, which represents a minor per capita saving of 0·5 l/day.
- Compulsory metering of unmeasured households that are high water users or on change of occupancy, or metering of remaining unmeasured non-households.

Use of greywater recycling was discounted because of high installation and maintenance costs, the high energy requirements and the potential health risks. Also, some of the supply side management options (e.g. increasing abstraction from river

	2006/2007	2034/2035
Total population served (000s)	6807	7700
Total households served (000s)	2936	3581
Dry weather year average per capita water consumption: l/day	149	145
Dry weather year demand: Ml/day	1014	1117

Table 2. Population, household and domestic demand trend for the integrated zone

sources or groundwater, desalination, new reservoirs, etc.) have been discarded as being unpromotable due to environmental concerns, unless no practical alternative options exist. However, in addition to reduction of 26·9 Ml/day by means of leakage control and water efficiency measures, other water source enhancements are required to eliminate the remaining deficit (47·7 Ml/day).

3. Resilience of sustainable water management solutions

As listed above, the 'efficient use of water' and 'sustainable urban drainage' have been mentioned as two possible options in the planning guidance for the site. However, the guidance is not specific regarding the means that can be employed to mitigate surface water run-off impacts and reduce demand on potable water supply. The review of planning documents showed that some measures have been taken to address the flood risk in the proposed development; however, reducing pressure on natural resources and water infrastructure and their impact on the environment have not been explored. In the following sections, the current and projected supply–demand balance for the supply area will be discussed. A further four scenarios will be analysed, exploring the influence of future values of water and planning factors (i.e. housing/population growth, changes in the per capita consumption, sustainability reduction and climate change impacts).

3.1 Current resilience

The emergency storage allowance adopted for the integrated resource zone is 20 days (64·8 Ml/day), which is towards the lower end of the range (15–45 days) suggested in the Environment Agency's guidance (United Utilities, 2009). Recent extreme events have demonstrated how vulnerable these systems are and there is a greater need to improve their resilience. United Utilities imposed a hosepipe ban in the summer of 2010 following the driest start to the year since its records began in 1929. It was the first hosepipe ban in north west England for 14 years. The ban restricted the use of hosepipes or sprinklers for watering private gardens and washing private cars. Despite actions such as maximising water abstraction from groundwater supplies and moving water around the supply zone to maintain essential supplies, and some rainfall, reservoir levels remained significantly low resulting in a 6-week hosepipe ban. It has been reported that approximately 4 billion litres (95·2 Ml/day) of water was saved during the ban (United Utilities, 2010a).

Towards the end of 2010, after a long period of very cold weather, thaw caused disruption to water supply systems. Melting ice moved the ground, putting unusual amounts of stress on the pipes. This caused some of the pipes to leak or burst and therefore resulting in loss of water and significant interruption in water supply (United Utilities, 2010b). The above-mentioned extreme conditions are good examples of the need to improve the resilience and adaptability of water systems and resources to future uncertainties.

3.2 Future resilience

Population growth, particularly in urban areas, changing lifestyles to more water-intensive ones and climate change are some of the primary factors leading to the growing deficit between the available water resources and demands (EA, 2009b). For example, summer precipitation is predicted to fall in north west England due to global warming and under the high emissions scenario the fall could be 19% by the 2020s and 37% and 50% by the 2050s and 2080s, respectively (Defra, 2009). Summer and winter mean temperatures are predicted to rise for north west England. Therefore, climate change alone could increase supply–demand imbalance as shown in the review of the United Utilities' analysis. These vulnerabilities highlight the need to improve the resilience of current solutions to the potential effects of changes in the future.

Future scenarios are used as a tool for describing the future as it might be; they are neither forecast nor predictions, and explicitly do not include trend analysis. They help to account better for the impact that future changes are going to have on current solutions, allowing for exploration of variability and more extreme futures (Butler, 2004). In this work, using the urban futures methodology, as outlined in Boyko *et al.* (2011) and Rogers *et al.* (2012), the relative resilience of current solutions to future changes is assessed. The four scenarios adopted are listed below.

- Market forces (MF): Well-functioning markets are argued to be the key to resolving social, economic and environmental problems. This future assumes the global system in the twenty-first century evolves without major surprise and incremental market adjustments are able to cope with social, economic and environmental problems as they arise.
- Policy reform (PR): This future assumes that markets require strong policy guidance to address inherent tendencies towards economic crisis, social conflict and environmental degradation. The tension between continuity of dominant values and greater equity for addressing key sustainability goals will not be easily reconciled.
- New sustainability paradigm (NSP): New social-economic arrangements and fundamental changes in values result in changes to the character of urban industrial civilisation, rather than its replacement.
- Fortress world (FW): This is a future in which the world is divided, with the elite in interconnected, protected enclaves and an impoverished majority outside. Armed forces impose order, protect the environment and prevent a collapse.

Scenario	PR	MF	NSP	FW
Per capita consumption change: %	−20	+5	−30	−10
Population change: %	+35	+45	+25	+20

FW = fortress world; MF = market forces; NSP = new sustainability paradigm; PR = policy reform

Table 3. 2050s per capita consumption and population changes from now under the four scenarios

The four futures are based on the Global Scenario Group scenarios (Kemp-Benedict *et al.*, 2002) that focus on quantitative variables across a wide range of socioeconomic and environmental factors (e.g. population, economy, environment, etc.) and were a practical starting point for this analysis. However, the Environment Agency has developed each of these four scenarios into a more detailed picture of future water demand, based on factors such as policy, technology and user behaviour and their influence on micro-component demand for water appliances at household level (EA, 2006, 2009c). The Office of National Statistics (ONS, 2007) information on population in 2030, 2050 and 2080 was used in connection with qualitative information about fertility, life expectancy and migration for each scenario to estimate population under each scenario and therefore estimate demand. Table 3 summarises the overall output of the Environment Agency's study on water demand and population growth, which will be used in this paper. The second and third rows refer to the percentage of change in the per capita consumption and population, respectively, under each scenario.

The dry year average per capita water consumption of 149 l/day (for 2006/2007, Table 2) was used as the base data in conjunction with the change rates for per capita consumption (Table 3) to calculate per capita consumption demands of 120, 156, 104 and 134 l/day under PR, MF, NSP and FW scenarios, respectively. Table 4 presents the water company's projections of supply–demand balance and the corresponding calculations for the four scenarios based on the dry year water demand. Assuming the same water resources availability, the results show a deficit of −60·6 and −497·6 Ml/day for supply–demand balance based on demand change for the integrated zone under PR and MF and a surplus of 157·4 and 52·6 Ml/day under NSP and FW, respectively. A similar analysis, at the case study site level, has been presented in an accompanying paper within this special edition (Hunt *et al.*, 2012).

4. Futures analysis

As described by Rogers *et al.* (2012), the urban futures methodology requires the necessary conditions for each intended benefit to be identified and considered against the characteristics of the four plausible futures.

4.1 Identification of a sustainability solution and its intended benefit

To avoid unacceptable deficits in the supply and demand balance, it is necessary to assess various scenarios for potential reduction to water demand from off-site sources by considering an integrated approach to management and conservation of water. The aim is to explore strategies that are acceptable to

	Baseline	Water company's projection 2035	PR	MF	NSP	FW
Per capita consumption: l/day	149	145	120	156	104	134
Population (000s)	6807	7700	9189	9870	8509	8168
Total demand: Ml/day	1014	1117	1103	1540	885	1095
Supply–demand balance: Ml/day		−74·6	−60·6	−497·6	157·4	52·6

FW = fortress world; MF = market forces; NSP = new sustainability paradigm; PR = policy reform

Table 4. Supply–demand balance under the four scenarios for the integrated zone (water-efficient appliances)

end users and each delivers a range of benefits. Examples are given below.

- Demand reduction delivers value in terms of cost per cubic metre of water saved, reduces strain on both water and sewer systems and reduces energy demand.
- Rainwater harvesting saves large volume of mains (potable) water and prevents similar volumes of water entering the stormwater system resulting in financial and ecological benefits. Rainwater harvesting can save up to 50% of domestic water demand (Hunt *et al.*, 2012); however, the yield is uncertain. The effects of seasonal variation can be reduced by increasing the size of the storage reservoir in rainwater harvesting systems, which can be designed to store water for up to 21 days (BSI, 2009).
- Greywater recycling for water closet flushing has the potential to save up to 30% of domestic water demand (Eriksson *et al.*, 2002; Hunt *et al.*, 2012) and provide a reliable and continuous source of supply. However, financial gains will be small as the payback period is long. Water can be stored for up to 24 h, after which the water must be sent to the drain (BSI, 2010). Greywater recycling is an effective option for buildings with a consistent supply of wastewater and limited roof areas such as high rises and buildings in densely populated areas.

Greywater recycling and rainwater harvesting solutions can also reduce the demand on rivers and groundwater and thus reduce the need for energy and chemicals to produce potable water where it is not needed. They also reduce the risk of localised (pluvial) flooding if adopted at a wide scale.

4.2 Identification of the necessary conditions

4.2.1 Social acceptability of water-efficient appliances

Although the above-mentioned technologies allow water efficiency and conservation, their success often depends on users' behaviour. Water efficiency typically takes the form of low flow showers and taps, dual-flush toilets, smaller baths and basins. Estimates shows that dual-flush cistern water closets with flush volumes of 6/4 litres represent 88% of all sales in the UK according to the Market Transformation Programme (MTP, 2011a). Electric showers are estimated to represent approximately 46% of all showers installed in the UK (Critchley and Phipps, 2007). Essex and Suffolk Water (ESW, 2006) researched shower type, use and habits and found that 92% of the users were satisfied with their electric showers despite the limited flow rate. Research undertaken by water utilities in the UK has shown that the average volume of water used per bath is approximately 65–100 litres (MTP, 2011b). Low consumption dishwashers and washing machines can be used to reduce further the demand for potable water. The majority of the dishwashers currently in the UK market are efficient due to industry commitments, in 2000 and 2003, to remove the least efficient products from the market.

4.2.2 Social acceptability of water-efficient technologies

Further potable water savings can potentially be achieved through the use of water recycling and reuse. Ward (Rainwater harvesting in the UK: a strategic framework to enable transition from novel to mainstream, unpublished PhD thesis, University of Exeter, 2010) carried out a survey on acceptability of rainwater harvesting as opposed to greywater recycling and different collection areas (i.e. own home as opposed to neighbours' home). This survey showed that the order of preference (most preferable to least) was

(*a*) rainwater harvesting own roof
(*b*) rainwater harvesting neighbour's roof
(*c*) greywater recycling own house
(*d*) greywater recycling neighbour's house.

In another survey by Friedler *et al.* (2006) on attitudes towards various wastewater reuse options, it was indicated that reuse in office and domestic toilet flushing was acceptable by 86% and 79% of 256 questionnaire respondents, respectively. For public parks and private garden irrigations acceptability was at 92% and 80%, respectively. Finally, for high contact options such as domestic washing machines, the acceptability was lower at 45%.

4.3 Assessment of the necessary conditions against scenario characteristics

Using the urban futures methodology, greywater recycling and rainwater harvesting solutions are interrogated further in order to ascertain whether their intended benefits can continue to be delivered in the future. Table 5 provides a completed matrix that can be used to understand better whether the necessary conditions remain in place, change or no longer exist in these four futures. In the table, '✓' indicates that the necessary condition remains and the solution continues to provide benefits and '?' shows that the necessary condition may change therefore a vulnerability may exist with the solution providing intended benefits. '✗' indicates that the necessary conditions no longer exist or have changed to a prohibitive degree whereby the intended benefit is not deliverable. Hunt *et al.* (2012) provide a quantitative evidence base to show how these sustainability solutions perform when changes in necessary conditions related to technological efficiency alone are considered.

Although potable water demand savings of up to 50% from rainwater harvesting (Hunt *et al.*, 2012) and 30% from greywater recycling (Eriksson *et al.*, 2002; Hunt *et al.*, 2012)

Necessary conditions*	PR	MF	NSP	FW
Non-potable demands must exist [a, b]	**?** Policy emphasises adoption of highly water-efficient technologies (behaviour unchanged) and non-potable demands reduce	✓ Water-using behaviour and technological inefficiency remain relatively unchanged therefore non-potable demands remain high	**?** Sustainable water-using behaviour and adoption of highly water-efficient technologies (adopted willingly) significantly reduce non-potable demands	✓ Non-potable demands are high for the haves (technology and behaviour mirrors MF) and low for the have nots (necessity drives extremely low water-using behaviour)
Enough water must be collected to meet non-potable demands[a]	**?** Adoption of green roofs and compact development will compromise RWH in terms of water quality and quantity	✓ No change roof type/ area and low density, fragmented development expected hence ability to RWH is unchanged	? Adoption of green roofs and high density development will compromise RWH in terms of water quality and quantity	✓ Low density, fragmented development for haves hence ability to RWH is unchanged ? In dense 'high occupancy' have nots areas the amount of available rainwater per person decreases, however, non-potable demands are low. Hence enough water could probably be collected
Enough water must be collected to meet non-potable demands[b]	✓ Adoption of highly water-efficient technologies alone reduces GW production hence collection, non-potable demands can be met	✓ Adoption of more luxury appliances increases significantly GW production hence collection. Non-potable demands can be met	**?** Adoption of highly efficient water technologies combined with more sustainable behaviour reduces significantly GW production hence collection, possibly below the level needed to meet demand	✓ GW production is increased for the haves (technology and behaviour mirrors MF) and decreased for the have nots (extremely low water-using behaviour goes far beyond NSP)
Enough water must be stored (for supply)[a]	**?** With supplies unchanged and demands reduced more water is available for storage	**?** With supplies unchanged and demands increased less water is available for storage	✓ With supplies unchanged and demands significantly reduced, more water is available for storage	**?** There is sufficient water for haves (mirrors MF). Have nots adopt undersized tanks due to lack of space meaning insufficient water is being stored
Enough water must be stored (for supply)[b]	✓ Enough GW is stored to meet non-potable demands within the home every day. Surplus GW is available	✓ Enough GW is stored to meet non-potable demands within the home every day. Significant volumes of surplus GW are available	**?** Provided non-potable demands decrease at the same rate as GW supplies enough water will be stored each day to meet non-potable demands	✓ Enough GW is stored to meet non-potable demands for haves every day

FW = fortress world; GW = greywater; MF = market forces; NSP = new sustainability paradigm; PR = policy reform; RWH = rainwater harvesting

Table 5. Urban futures analysis of greywater recycling and rainwater harvesting solutions (superscripts 'a' and 'b' refer to rainwater harvesting and greywater recycling, respectively) (continued on next page)

Necessary conditions*	PR	MF	NSP	FW
Enough spare storage capacity must be left (for flash flood protection)[a]	**?** High density development means not enough space for storage. Tank is full in winter and empty in summer months. Flash flood protection is offered from this solution in summer months only. Stormwater outflow is reduced	✓ Low density, fragmented development means enough space for storage. Tank is empty most months of the year. Flash flood protection is available from this solution all year round. Stormwater outflow is reduced significantly	✗ High density development means not enough space for storage. Tanks remain full year round – hence no flash flood protection is offered through this solution any time during the year. Stormwater outflow is little changed	✓ Low density, fragmented development for haves means enough space for storage **?** Small tanks for have nots frequently empty and fill throughout the year having little impact on reducing flash flooding. Stormwater outflow is little changed
Related infrastructure must remain in place[a, b]	✓ Large scale infrastructure will remain in place. Modification is unlikely (demand decreases; however, this is balanced out by an increase in urban populations)	✓ Infrastructure will remain provided maintenance costs are not prohibitively large. Future expansion of mains supplies and wastewater systems likely in order to meet increasing urbanised demands	**?** Infrastructure will remain in place; however, modification to water wastewater infrastructure may be required due to reduced demand and possible water quality problems or redesign due to changes in urban form (high density, polycentric developments)	✓ Supplies need to be secured hence large infrastructure systems are likely to remain in place for have nots ? Small scale infrastructure will probably be required for haves
System must be publicly acceptable[a, b]	✓ Acceptability is dependent upon the strength of policy in place. RWH is likely to be more willingly adopted than GW	✗ Acceptability is likely to be low as householders are unwilling to take any responsibility (or risk) for sourcing their own water supplies	✓ Public acceptability is high. The reasons for sustainable water sourcing are widely understood and accepted. Using other people's GW is probably now acceptable	**?** Acceptability is driven through measures to ensure security of supply for both haves and have nots
System must be economically viable[a, b]	**?** Reduced volumes of mains water are being substituted for non-potable water. Payback is slower than MF but quicker than NSP. Increased water tariffs probably invoke change	✓ Increased volumes of mains water are substituted for non-potable water hence payback period is relatively quick. However, mains water remains cheap to buy	✗ Significantly reduced volumes of mains water are being substituted for non-potable water hence payback periods are very slow	✓ Payback period is quick for haves (mirroring MF) and quick for have nots (systems are likely to be small, simple and cheap to buy as affordability for complex systems is unlikely)
Policy for adoption of systems must remain in place[a, b]	✓ Strong policies provide guidance on systems and are enforced readily – systems are integrated into new build and retrofitted elsewhere	✗ Policy is weak and there is no incentive for adopting or keeping non-potable systems, unless economic viability can be shown	✓ Policies remain in place, although enforcement is very rarely required – the population willingly adopt systems to facilitate an ethos of one planet living	✗ Policy does not drive adoption of systems for haves or have nots (who cannot afford it). Those who fail to adopt go without water
System must be maintained[a, b]	✓ Systems will be maintained on a schedule consistent with life expectancy	**?** Systems will be maintained on an ad hoc basis as and when required (e.g. failure)	✓ Systems will be rigorously monitored for signs of wear and continually maintained to avoid failure	**?** Supplies need to be secured hence systems are likely to be maintained for haves. Less likely for have nots

Table 5. Continued

	Baseline	Water company's projection 2035	PR	MF	NSP	FW
Per capita consumption: l/day	149	145	120	156	104	134
Population 000s	6807	7700	9189	9870	8509	8168
Total demand: Ml/day	1014	1117	1103	1540	885	1095
Potable demand replaced by non-potable: Ml/day		0	71·5	122·5	42·6	46·3
Supply–demand balance: Ml/day		−74·6	10·9	−375·1	200·0	98·9

FW = fortress world; MF = market forces; NSP = new sustainability paradigm; PR = policy reform

Table 6. Supply–demand balance under the four scenarios for the integrated zone (water-efficient appliances in all dwellings and rainwater harvesting and/or greywater recycling in new dwellings only)

have been reported, in this work a modest 25% of total demand under each scenario has been considered to be replaced by reused/recycled water in the future analysis. Table 6 summarises the supply–demand balance considering water efficiency measures for all domestic dwellings (based on EA, 2009c) and rainwater harvesting and/or greywater recycling only for new domestic dwellings. It is shown that three out of four scenarios will have surplus resources if 25% of potable domestic water demand for new dwellings is replaced by non-potable water. Under MF, there is still some deficit; however, as shown in Table 5, the majority of the necessary conditions are in place to save more water under this scenario if policy or user behaviour changes. Future analysis also shows that the sustainable water strategies can deliver their intended benefits when they are most needed (MF and FW futures) as most necessary conditions are in place except user behaviour and policy.

5. Conclusion

Potential impacts and constraints associated with local water management at a proposed urban regeneration site in north west England were assessed with regard to the key issues of water resources and supply–demand balance at regional level. Water-efficient strategies in combination with rainwater harvesting or greywater reuse were compared, in terms of water savings/yield, and benefits as well as their resilience to a range of possible changes in the future using an urban futures methodology. It was found that, contrary to expectations, at least some of the local strategies should deliver their full intended benefits under scenarios least expected. Despite being heavily constrained by local context and a complex regulatory environment, it is still feasible and effective to incorporate local demand management measures in the proposed urban regeneration site as a contribution to reducing pressure on regional water resources and contributing towards wider sustainability objectives. The use of a diverse range of water management options is recommended when possible to improve and increase overall system resilience in the face of an uncertain future.

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REFERENCES

Boyko CT, Gaterell MR, Barber ARG, *et al.* (2012) Benchmarking sustainability in cities: The role of indicators and future scenarios. *Global Environmental Change* **22(1)**: 245–254.

BSI (2009) BS 8515: Rainwater harvesting systems. Code of practice. ISBN 978 0 580 60490 4. BSI, London, UK.

BSI (2010) BS 8525: Greywater systems – Part 1: code of practice. ISBN 978 0 580 63475 8. BSI, London, UK.

Butler D (2004) Urban water – future trends and issues. *Proceedings of British Hydrological Society International Conference, Hydrology: Science and Practice for the 21st Century, London*. (Webb B *et al.* (eds)), vol. 2, pp. 233–242.

Butler D, Farmani R and Abdelmeguid H (2011) Optioneering development-scale water systems. *The Future of Urban Water: Solutions for Livable and Resilient Cities, UNESCO, Paris*, 24–26 January 2011. CD-ROM.

CLG (Department of Communities and Local Government) (2010a) *Planning Policy Statement 25 (PPS 25): Development and Flood Risk*. See http://www.communities.gov.uk/publications/planningandbuilding/pps25floodrisk (accessed 10/10/2011).

CLG (2010b) *Code for Sustainable Homes: Technical Guide 2010*. See http://www.planningportal.gov.uk/uploads/

code_for_sustainable_homes_techguide.pdf (accessed 10/10/2011).

Critchley R and Phipps D (2007) *Water and Energy Efficient Showers: Project Report*. United Utilities and Liverpool John Moores University. See http://www.unitedutilities.com/Documents/UULJMUwaterenergyefficientshowerFinalreport23rdMay2007.pdf (accessed 10/06/2011).

Defra (Department for Environment, Food and Rural Affairs) (2008) *Water Efficiency in New Buildings: A Joint Defra and Communities and Local Government Policy Statement*. See http://www.communities.gov.uk/documents/planningandbuilding/pdf/WaterEfficiencyNewBuildings.pdf (accessed 10/10/2011).

Defra (2009) *UK Climate Projections*. See http://ukclimateprojections.defra.gov.uk (accessed 10/06/2011).

Defra (2010) *Flood and Water Management Act 2010*. See http://www.legislation.gov.uk/ukpga/2010/29/pdfs/ukpga_20100029_en.pdf (accessed 10/10/2011).

EA (Environment Agency) (2003) *Brownfield Land Redevelopment: Position Statement*. EA, Bristol, UK. See http://www.environment-agency.gov.uk/research/library/position/41237.aspx (accessed 10/10/2011).

EA (2006) *Environment Agency Scenarios 2030, Science Report SC050002/SR1*. Available from enquiries@environment-agency.gov.uk. EA, Bristol, UK.

EA (2009a) *Water Cycle Study Guidance*. EA, Bristol, UK. See http://publications.environment-agency.gov.uk/PDF/GEHO0109BPFF-E-E.pdf (accessed 10/10/2011).

EA (2009b) *Water for People and the Environment. Water Resources Strategy for England and Wales*. EA, Bristol, UK. See http://publications.environment-agency.gov.uk/PDF/GEHO0309BPKX-E-E.pdf (accessed 10/10/2011).

EA (2009c) *Demand for Water in the 2050s: Briefing Note*. EA, Bristol, UK. See http://publications.environment-agency.gov.uk/pdf/GEHO1208BPBY-E-E.pdf (accessed 10/10/2011).

EC Environment (2000) *The EU Water Framework Directive – Integrated River Basin Management for Europe*. See http://ec.europa.eu/environment/water/water-framework/index_en.html (accessed 10/10/2011).

Eriksson E, Auffarth K, Henze M and Ledin A (2002) Characteristics of grey wastewater. *Urban Water* **4(1)**: 85–104.

ESW (Essex and Suffolk Water) (2006) *Showers Types Use and Habits, Final Report*. See http://www.eswater.co.uk/ESWfinalreport.pdf (accessed 10/06/2011).

Friedler E, Lahav O, Jizhaki H and Lahav T (2006) Study of urban population attitudes towards various wastewater reuse options: Israel as a case study. *Journal of Environmental Management* **81(4)**: 360–370.

Hunt DVL, Lombardi DR, Farmani R, *et al.* (2012) Urban futures and the code for sustainable homes. *Proceedings of the Instution of Civil Engineers – Engineering Sustainability*. **165(1)**: 37–58.

Kemp-Benedict E, Heaps C, Raskin P (2002) *Global Scenario Group Futures, Technical Notes*. Boston: Stockholm Environmental Institute, Tellus Institute. PoleStar Series Report no. 9. GSG,

LCC (Lancaster City Council) (2004) *Supplementary Planning Guidance Note 4, Luneside East Development Brief (Revised)*. Lancaster City Council, Lancaster, UK.

LCC (2007) *Sustainable Appraisal: Core Strategy Submission Document*. Lancaster City Council, Lancaster, UK.

MTP (Market Transformation Programme) (2011a) *BNWAT01 WCs: Market Projections and Product Details*. Market Transformation Programme, Defra, London, UK.

MTP (2011b) *BNWAT03 Baths: Market Projections and Product Details.* Market Transformation Programme, Defra, London, UK.

ODPM (Office of the Deputy Prime Minister) (2003) *Sustainable Communities: Building for the Future*. See http://www.communities.gov.uk/documents/communities/pdf/146289.pdf (accessed 10/10/2011).

ONS (Office for National Statistics) (2007) *2006-Based National Population Projections*. The Office for National Statistics.

Rogers CDF, Lombardi DR, Leach JM and Cooper RFD (2012) The urban futures methodology applied to urban regeneration. *Proceedings of the Institution of Civil Engineers – Engineering Sustainability* **165(1):** 5–20.

United Utilities (2009) *Final Water Resources Management Plan*. See http://www.unitedutilities.com/WaterResourcesPlan.aspx (accessed 10/10/2011).

United Utilities (2010a) *Hosepipe Ban Lift*. See http://www.unitedutilities.com/6748.aspx (accessed 10/10/2011).

United Utilities (2010b) *After the Big Freeze … the Big Thaw*. See http://www.unitedutilities.com/7436.aspx (accessed 10/10/2011).

United Utilities (2011) *West East Link Pipeline*. See http://welm.unitedutilities.com/index.aspx (accessed 10/10/2011).

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