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# Testing the Resilience of Underground Infrastructure Solutions through an Urban Futures Methodology

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## 1 ABSTRACT

Resilience engineering is about building in sufficient flexibility whist ensuring that outcomes are robust. As such it is a measure of the ability of Urban Engineers to provide solutions today that can cope (i.e. adapt) to real world complexity ensuring they remain relevant no matter what the future holds. Success in this area is undoubtedly related to the ability of Urban Engineers to define current operating conditions and anticipate more fully how these may change in the future. In so doing, risk of failure or breakdown within any given solution is reduced, a better understanding of what might trigger such threats to occur is highlighted, and necessary adjustments (either now or in the future) are identified; in short the resilience of the solution is improved.

This paper presents an Urban Futures (UF) methodology that facilitates testing the future resilience of any underground water infrastructure solution (e.g. potable and non-potable mains water, wastewater and stormwater). Through the use of 5 scenarios (1 baseline and 4 plausable futures each considering increasing technological water efficiency in the home) the resilience of localised rainwater harvesting infrastructure is tested at four city locations within Europe (i.e. Birmingham - UK, Lancaster - UK, Barcelona – Spain and Malmö – Sweden). In so doing a methodological approach to robustly test the resilience of any underground infrastructure asset is defined, and it is shown that so called 'sustainability' solutions may provide varying degrees of resilience in each scenario and location.

## 2 INTRODUCTION

Urban water provision and investment are predicated on trend analysis, where future demand forecasts rely upon what we know now. Unfortunately, the future is never certain and rarely conforms to set trends, therefore the infrastructure which is being adopted today in the name of sustainability may be vulnerable in a future which resides outside the limits of current predictions. Moreover an infrastructure solution that has been optimised for sustainable benefits today may not be resilient (or even sustainable) if operating conditions dramatically change. In responding to this challenge it is suggested that Urban Engineers might seek to provide infrastructure solutions today that can cope (i.e. adapt) to real world complexities ensuring they remain relevant no matter what the future holds. Some engineers would advocate that built-in flexibility (or redundancy) will always propogate robust future outcomes (O'Rourke, 2007). Although this is reliant upon Urban Engineers defining current infrastructure operating conditions and anticipating more fully their potential for future change (i.e. for better but also for worse). Through the use of a worked example this paper presents a five-stage Urban Futures (UF) methodology (Section 3) that can be used to explore a variety of ways in which the operating conditions of a localised underground infrastructure solution (i.e. non-potable rainwater harvesting - RWH) may change in the future and helps evaluate how this could trigger threats/risks not only to its own resilience but also the resilience of other adjoining infrastructure networks (e.g. mains potable water supply, wastewater and stormwater systems). A better understanding of what might trigger such threats to occur is highlighted, and necessary adjustments (either now or in the future) are identified; in short the resilience of the RWH solution is improved. Allied to this process is the application of an UF tool, initially developed to test the performance of water-based solutions - through scenario-based analysis (i.e. normative or explorative) where social, technological and environmental changes are considered.

## 3 URBAN FUTURES (UF) METHODOLOGY

The Urban Futures (UF) methodology, as originally described by Rogers et al. (2012), consists of five discrete stages that are for the most part linear (Figure 1). In this paper the methodology has been adapted for testing the resilience of underground infrastructure solutions and shows clearly where the UF tool is applied. Stages 1 to 5 are explained through the use of a worked example.

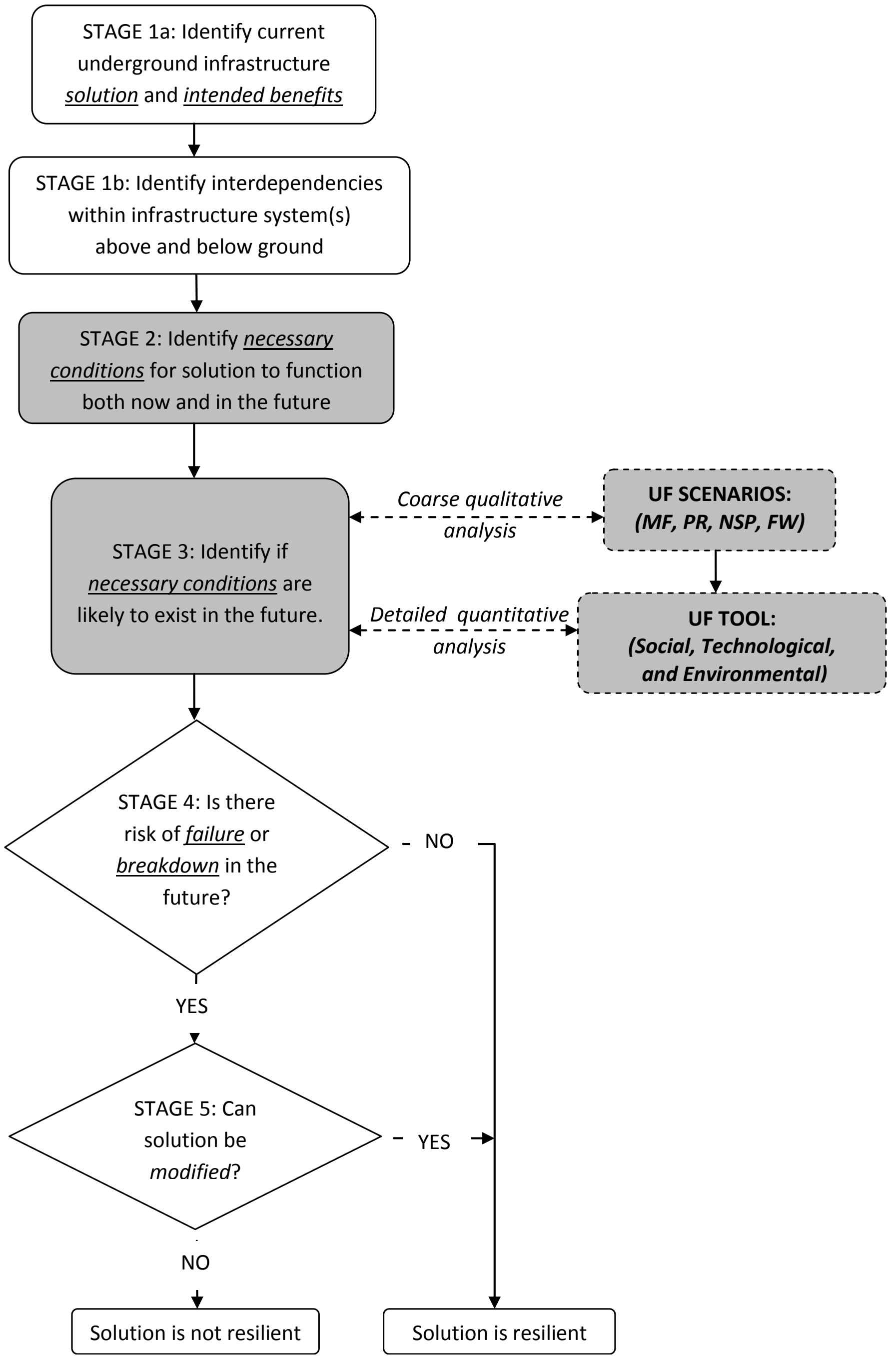


Fig 1: Urban Futures methodology as applied to urban infrastructure

### 3.1 Stage 1a – Identify underground infrastructure solution(s) and sustainability benefits.

Underground infrastructure solutions can be selected in one of two ways; either planners/developers/infrastructure engineers are aware of a specific problem(s) within urban areas and seek sustainable solution(s); alternatively solution(s) have been adopted without any prior knowledge of their sustainability function/benefits and/or current and future problem(s).

In this example urban engineers have proposed the introduction of an underground non-potable water supply network (i.e. rainwater harvesting – RWH, Figure 2) in order to achieve the following sustainability benefits within the local area (Hunt et al., 2012a):

- Reduced consumption of potable (i.e. drinkable) mains water;
- Reduced requirements for stormwater outflow;
- Increased water storage in times of drought and mains water failure;

- Increased pluvial flash flood protection.

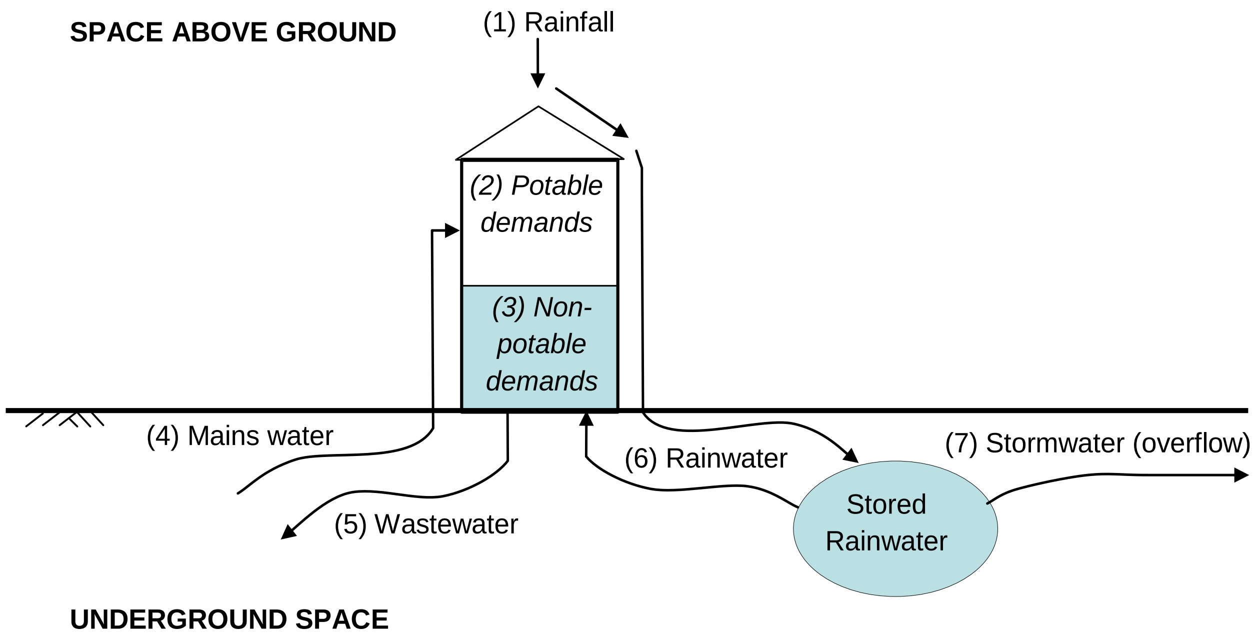


Fig 2: Key elements for RWH infrastructure

### 3.2 Stage 1b - Identify interdependencies above and below ground

By narrowing down the analysis to the scale of an individual domestic dwelling (Figure 2) we can easilly identify key interdependencies that are directly related to the adoption of an RWH system. Each of these interdependencies will ultimately impact upon the use of space above and below ground, which in urban areas is becoming increasingly compact.

- Within the house the numerous daily water related demands per person (e.g. cooking, washing, cleaning) are dependent upon the technologies adopted (e.g. a shower with 12l/s flow rate), the frequency of use (e.g. once a day) and longevity of use (e.g. a 5 minute shower). The total household demand is directly dependant on occupancy rates. Changes to any one of these influencing factors will impact greatly upon all inflows and outfloes therefore related infrastructure requirements (4 to 7 in Figure 2). In turn this will influence the resilience of localised and non-localised utility infrastructure which is conventionally placed underground.
- Potable demands (2 in Figure 2), e.g. showering, are met through drinking quality water and are therefore dependent upon mains water supplies (4 in Figure 2). Conversley non-potable demands (3 in Figure 2), e.g. toilet flushing, are dependent upon harvested rainfall supplies (6 in Figure 2). Wastewater capacity (5 in Figure 2) is directly dependent upon both of these.
- The performance of an RWH system is highly dependent upon rainwater being collected (from a domestic roof) and stored within an underground tank, from where it is pumped to the point of demand. Any changes in rainfall (1 in Figure 2) will impact greatly upon the volumes of water that can be collected/stored. Subsequently this effects the ability of the RWH system to meet non-potable demands. When the tank reaches its capacity excess rainwater will overflow into the stormwater system. The volume and frequency of overflow (7 in Figure 2) is highly dependent upon how much water is coming in (i.e. rainfall), how much is being drawn off (i.e. non-potable demands) and the size of the RWH tank and roof. Correctly sizing these is important, because one requires a significant amount of underground space (~1-2m3 per household) and together a dual resilience role is served (i.e. to maximise potential for non-potable supplies and minimise stormwater outflow).

The most important point to highlight here is that any of these interdependent properties will change with location and are likely not static in the future. Therefore difficulties will undoubtedly arise when trying to understand (and quantify) what is happening to all inflows and outflows within a highly interdependent and somewhat complex system where changes in one area can have repurcussions in another. This is why the development and application of the UF tool is so very important. Whilst the example of a single domestic house is given here for simplicity outputs can be scaled-up within the UF tool (i.e. multiple dwellings of numerous types) so as to be representative of a (re)develeopment site or ultimately as part of a city.

### 3.3 Stage 2 - Identify necessary conditions for solution(s) to function.

This stage identifies the necessary conditions (NCs) that allow an RWH solution to function both now and in the future. Whilst in some cases these NCs will be straight forward to identify, others may require expert opinion (including validation through detailed modelling). However, in nearly all cases it is likely that NCs will be derived from (and subsequently influenced by) the following list of key drivers (Hunt et al., 2012a):

- **S**ocial (e.g. demographics, values, equity, public attitude, user-behavior)
- **T**echnology (e.g. type, efficiency)
- **E**nvironment **-** Natural and Built (e.g. climate, local resources, built form)
- **E**conomic (e.g. cost, affordability, payback)
- **P**olitics and Governance (e.g. regulations, laws, standards)

These NCs include, but are not limited to, the following list:

NC1 - Non-Potable demand must remain

NC2 - Enough water must be collected

NC3a - Enough water must be stored for supply

NC3b - Enough water must be stored for pluvial flash flood protection

NC4 - System must be economically viable

NC5 - System must be publically acceptable

NC6 - Policy for adoption of systems must remain in place

NC7 - Systems must be maintained

Some of these NCs are likely to be generically applicable anywhere in the world whilst others will be influenced greatly by, or simply explicit to, a particular location. This forms an obvious link with the theme of sustainability, where it is necessary to look at local, national and international requirements and impacts within economic, social and environmental spheres.

### 3.4 Stage 3 - Identify whether necessary conditions will exist in the future.

This stage determines whether the solution is likely to be effective in the future and forms a critical part of the resilience testing process (Rogers et al., 2012). In the UF methodology the future is envisioned through the use of four scenarios (Market Forces - MF, Policy Reform - PR, New Sustainability Paradigm - NSP and Fortress World - $FW_{HAVES\ (H)}$ or $FW_{HAVE\ NOTS\ (HN)}$) that are plausible, yet significantly different from each other and well-grounded within academic literature (Hunt et al., 2012b, Boyko et al., 2012). Rogers et al., (2012) showed that it is possible to identify whether NCs are vulnerable in the future through the use of contextual scenario-based narratives that include consideration of key drivers (Stage 2). Hunt et al. (2012a) found that this level of analysis was sufficient for identifying vulnerabilities in some NCs (i.e. NC5 to NC7) and would allow the user to confidently pass from Stage 3 to Stage 4. However, within NC1 to NC4 they highlighted that more detailed analysis may be required in order to understand better the vulnerabilities that exist. As such the generic excel-based UF tool (Figure 1) was subsequently developed in order to consider more easily the effect of making changes to social, technological and environmental drivers - all highly influential considerations within UF research. As described in Section 3.2 household water demands (hence water inflows and wastewater outflow) are influenced directly by a mix of technological efficiency and user-behaviour which in the future are relatively unknown quantities. By using these 'axes of uncertainty' we can produce a defined parametric space (Figure 3) within which to test the performance (and therefore resilience) of an RWH solution. Therein we can see that future demands may stay constant (anywhere along the dotted line), increase in value (area above dotted line) or decrease in value (area below dotted line). The UF scenarios (grey ovals) are shown within this parametric space and it can be seen that they allow us to test extremes, moreover they allow us to consider the case where households have the same demand values (NSP and $FW_{HN}$) although for very different reasons. The 5 scenarios being considered here (A to E) allow us to better understand the resilience implications along one axis of uncertainty (i.e. where technological efficiency alone is changing). In this case A refers to a scenario where technologicial efficiency is reduced compared to the Baseline B, whereas C, D and E refer to scenarios where progressively more water-efficient technologies are being adopted. The various input values for Scenarios A to E are shown in Table 2 and Table 3, a broader discussion of which follows.

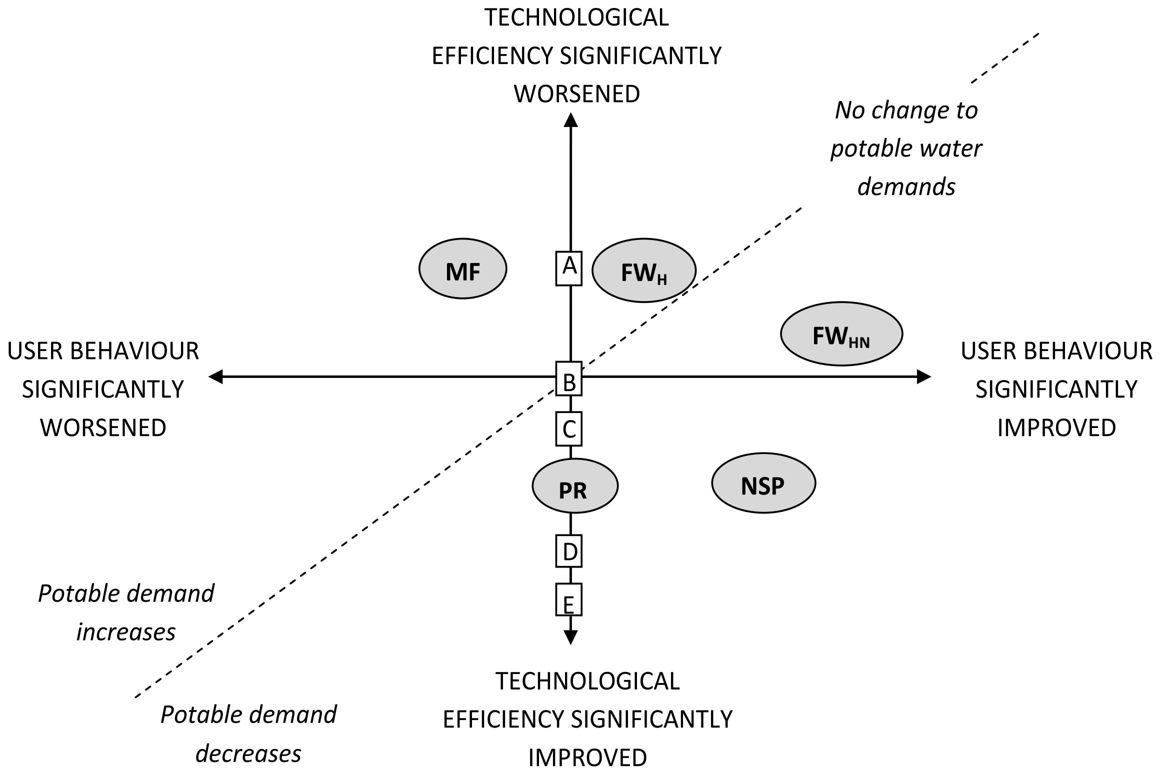


Fig 3: Parameter space required for resilience testing in UF analyses

| **Driver** | **Operating condition(s)** | | ***Units of measure*** | **Scenarios** | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **A** | **B** | **C** | **D** | **E** |
| Environment | Climate | Rainfall | *mm/day* | Figure 3a (Lancaster scenarios) | | | | |
| | | | *mm/day* | Figure 3b (Birmingham scenarios) | | | | |
| | | | *mm/day* | Figure 3c (Barcelona scenarios) | | | | |
| | | | *mm/day* | Figure 3d (Malmö scenarios) | | | | |
| | Built form | Roof space | *$m^2$* | 50 (all scenarios) | | | | |
| | | Roof type | *% water capture* | 90 (all scenarios) [5] | | | | |
| | | Roof material | *% water capture* | 90 (all scenarios) [5] | | | | |
| Social | Demographics | Occupancy | *Occupants/dwelling* | 2.4 (UK scenarios) [3] | | | | |
| | | | *Occupants/dwelling* | 2.6 (Barcelona scenarios) [4] | | | | |
| | | | *Occupants/dwelling* | 2.0 (Malmö scenarios) [3] | | | | |
| | End-user behaviour [2] | WC | *Flushes/day* | 4.42 (all scenarios) | | | | |
| | | Bath | *Capacity filled** | 0.11 (all scenarios) | | | | |
| | | Shower | *Minutes/shower** | 4.37 (all scenarios)** | | | | |
| | | Washing machine | *Frequency of use* | 2.10 (all scenarios) | | | | |
| | | Dishwasher | *Frequency of use* | 3.60 (all scenarios) | | | | |
| Technology | Technological efficiency [1] | WC | *Liter/flush* | 6 | 6 | 4.5 | 4.5 | 2.6 |
| | | Bath | *Liter capacity* | 230 | 230 | 230 | 160 | 97 |
| | | Shower | *Liters/minute* | 24 | 12 | 8 | 8 | 6 |
| | | Washing machine | *Liters/kg* | 13 | 13 | 10 | 6.1 | 6.1 |
| | | Dishwasher | *Liters/place setting* | 1 | 1 | 1 | 1 | 0.7 |
| | | **Total potable water demand** | *l/person/day* | 199 | 148 | 117 | 101 | 76 |
| | | **Total non-potable water demand** | *l/person/day* | 54 | 54 | 48 | 41 | 24 |

Table 2: Input values adopted within the UF tool. [References: 1Hunt et al., (2012a), 2 DCLG (2010), 3 NHBC (2010), 4 ECPF (2010), 5Leggett et al (2001), *Frequency of use not disagregated, ** Would increase to 5.1 if no bath adopted.]

### 6.1.1 3.4.1 Environment: Natural and Built

Local climates (e.g. rainfall, temperature, irradiance, wind speeds, etc.) are influenced greatly by geographical location and certainly within Europe can vary considerably throughout the year. In most respects this leads to reduced rainwater availability in hotter climates and during summer months. This paper uses the example of four European urban locations: Lancaster (UK), Birmingham (UK), Barcelona (Spain) and Malmö (Sweden), where climates vary markedly as shown in Figure 3a-3d. All aspects of roof design may be specific to a certain location and/or be dictated by local policy and this will influence how much rain can be collected. In order to limit the amount of variables within the analyses presented here it is assumed that roof types in all four locations are identical sizes (50 m2), pitched and tiled (Table 2). Therefore rainwater collection is merely a function of changing rainfall patterns in each location rather than roof design. The UF tool allows the user to generate any type of scenario and change potable and non-potable water demands and environmental operating conditions (Table 2). The impact on water infrastructure at various locations at different times in the year can then be assessed; this includes water inflows (i.e. mains water), water outflows (i.e. stormwater and wastewater), and tank storage (i.e. size of tank and water volumes stored). As stated previously all of these have implications for the use of underground space.

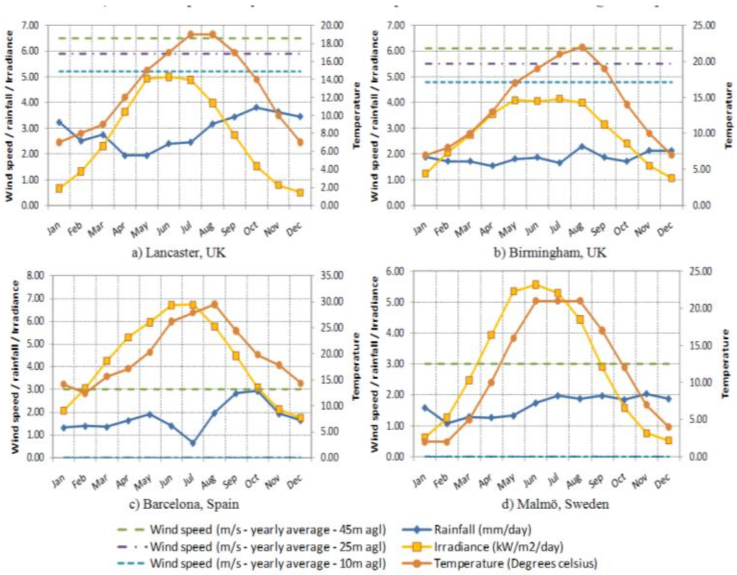


Figure 3. Local weather conditions in different locations

| Location | Demand type | *Units of measure* (hh = household) | Scenarios A | B | C | D | E |
|---|---|---|---|---|---|---|---|
| UK | Potable | *l/hh/day* | 418 | 311 | 246 | 212 | 160 |
| | Non-potable | *l/hh/day* | 113 | 113 | 101 | 86 | 50 |
| Spain | Potable | *l/hh/day* | 517 | 385 | 299 | 270 | 198 |
| | Non-potable | *l/hh/day* | 140 | **140** | 125 | 107 | 62 |
| Sweden | Potable | *l/hh/day* | 398 | 296 | 230 | 208 | 152 |
| | Non-potable | *l/hh/day* | 108 | 108 | 96 | 82 | 48 |

Table 3: Influence of occupancy rates on total household potable and non-potable demands.

### 6.1.2 3.4.2 Social

User behavior will impact considerably on future water demands within and outside the home. For example it is well reported that showering within the home is the largest consumer of water; showering for an average of 4.4 minutes in a 12 l/minute flow rate shower will consume 52.8 liters of mains water. Therefore changing shower times by 1 minute will change total demands by more than 10 liters. If the flow rate of the shower is changed also the cumulative effects would be considerable. This is true of many water-using appliances within the domestic home. In addition water-using behavior can be influenced greatly by climate, i.e. more frequent showering or car washing in warmer months (Roebuck, 2007) and if vegetables/plants/flowers/shrubs are grown at home (perhaps adopted in an aim to be more sustainable) significant water demands (i.e. >> the highest value of 199 l/person adopted in Scenario A) will be required during these periods. Occupancy rates, vary according to location (Table 2) and leed to highest demands (potable and non-potable) in Spain, followed by the UK and then Sweden (Table 3).

### 6.1.3 3.4.3 Technology

Future technologies adopted within the home form a significant contribution to total future water demands. As the efficiency of water-using appliances increases total water demands (including non-potable) will reduce and vice versa (Table 2, 3). Hunt et al. (2012a) showed that increases in domestic water demands from 149 l/person/day (Scenario B) to 199 l/person/day (scenario A) occurred through the adoption of power showers alone (24 l/minute flow rate), whereas reductions to 76 l/person/day (scenario C) required improved efficiency measures over a broader range of technologies including reduced flow rate showers (Table 2).

### 6.1.4 3.4.4 Politics, Economics and Governance

Whilst economics, policy and governance are important drivers their influence in this case is secondary. For example, a road map of policy requirements (gradually increasing in strength over time) could require that domestic demands to be decreased from 148 l/person/day to 80 l/person/day by 2014 and seek to implement this by rewarding uptake of more efficient technologies (and assuming behaviour is unchanged). In fact scenarios C, D and E do exactly this and are directly in line with Levels 1, 3 and 6 specified within the Code for Sustainable Homes in the UK, see Hunt et al., (2012a). Rather than addressing behavioural issues the preference in these scenarios is to enforce metering only. Alternatively policy may be extremely weak and inadvertantly encourage inefficient technologies to be adopted (Scenario A) or simply rely upon peoples' conscience to evoke a step-change in behaviour (e.g. In Feb, 2012 residents in South East UK were asked to reduce shower times by 1 minute due to fears of ensuing drought, but without strict policies in place how effective would this actually be?). Likewise economics (i.e. the rising cost of water) might influence the uptake of efficient technologies (for those who can afford the investment and will see a payback) or incentivise more water-efficient user-behaviour (for those who cannot). In such cases Government incentives can be used to bridge these gaps. Therefore when all influences are considered, it can be seen that water demand within a domestic home will always be directly dependent upon technological efficiency and user behaviour operating within spheres of environment constraints (i.e. availability of natural resources), policy requirements (i.e. those that seek to push or pull change) and economics (i.e. cost/value of water).

## 3.5 Stage 4 – Identifying future risks

In Stage 2 a range of NCs were identified. In this stage associated future risks to these NCs will be highlighted in order that their vulnerability (and therefore resilience of the solution) in all four locations are better understood. Table 2 shows that non-potable demands remain in the future, therefore there is likely to be a demand for non-potable water in the future, although to differing degrees in each scenario, hence NC1 is fulfilled. Provided that rain falls and RWH systems are implemented and working the ability of each location to collect rainwater (NC2) is fulfilled. However, the subsequent implications for water storage to meet demands (NC3a) and spare tank capacity to allow for flash flood protection (NC3b) is unclear and will vary drmatically within each scenario and within each location. In this paper we consider further risks related to NC3a and b. Risks associated with NC4 to NC7, are discussed further in Farmani et al. (2012). The effect of adopting the various demand profiles (Table 3) within each location is investigated through the use of the UF tool. Tanks (Table 4) are sized according to standard methods throughout (i.e. the greatest of 5 % annual rainfall and 5 % annual demand – BS8515; BSI, 2009).

| **Location** | **Scenarios** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| Lancaster, UK | 2063 | 2063 | 1567 | 1253 | 931 |
| Birmingham, UK | 1526 | 1526 | 1526 | 1253 | 931 |
| Barcelona, Spain | 1436 | **1436** | 1436 | 1436 | 1153 |
| Malmö, Sweden | 1359 | 1359 | 1359 | 1194 | 887 |

Fig. 4. RWH tank storage volumes (lhs) and related outflows to stormwater system (rhs) in different scenarios and case study locations


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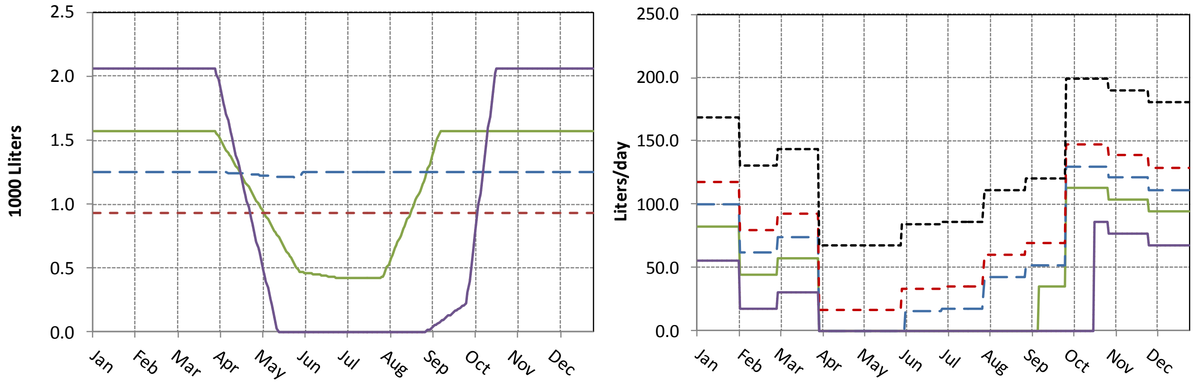
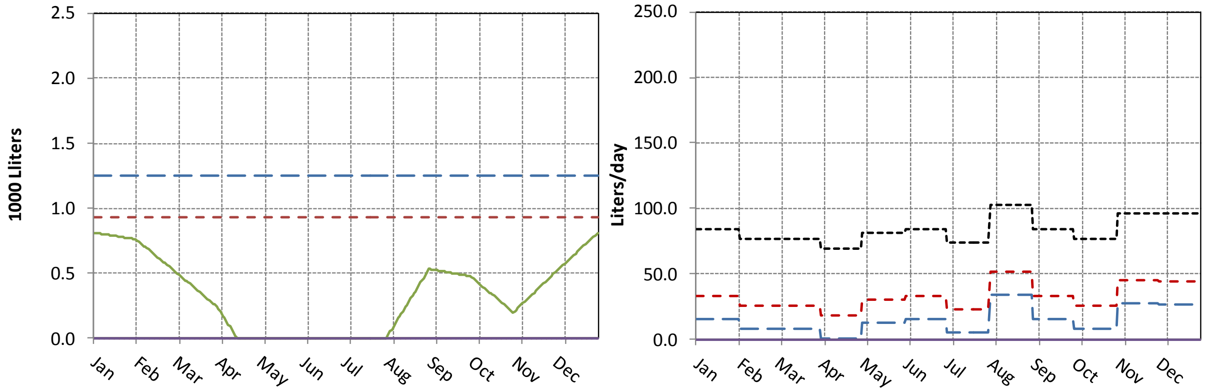
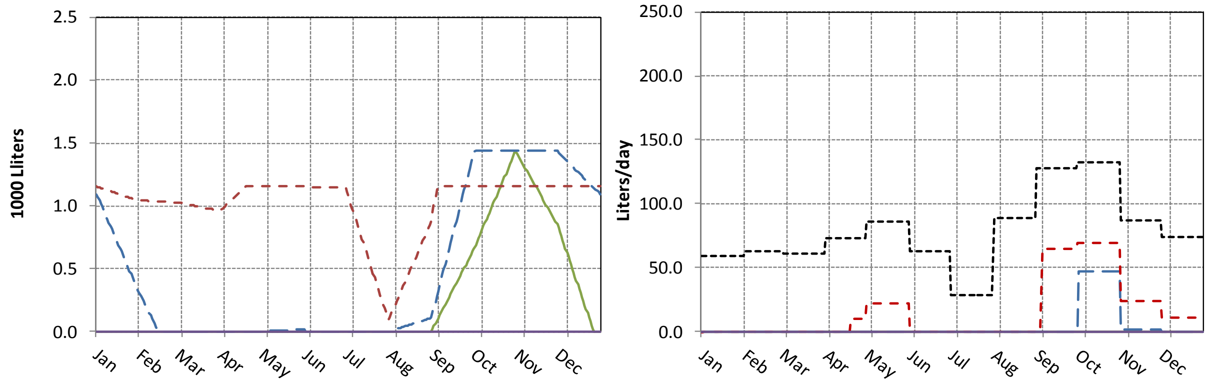


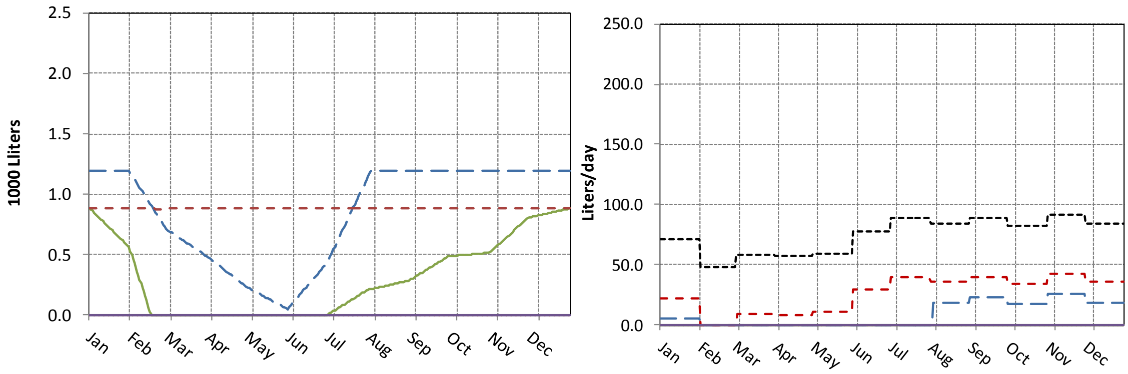

a) Lancaster, UK




b) Birmingham, UK




c) Barcelona, Spain




d) Malmö, Sweden

Table 5. Collection areas back-calculated from non-potable demands and rainfall (unrestricted tank size).


Fig 5. Influence of RWH roof size in Barcelona (a) 1436 liter RWH tank (b) RWH tanks sized for 5% annual rainfall

Figure 4a to d show the corresponding yearly water levels with RWH tanks and respective stormwater outflows within Scenarios A to E within all four case study locations. It is assumed that yield before storage occurs (Mitchell, 2007) and that tanks are installed in January. The data are presented for the 2nd year of installation thereby allowing tanks to fill and reach a steady state. However it should be recognised that average daily values of rainfall are used (calculated from monthly average values in Figure 3a to d), therefore results, whilst indicative, should be treated with care. Intuitively it can be seen that significant risk to NC3a will occur when RWH tanks are empty (i.e. not enough water to meet demand) and significant risk to NC3b will occur when the RWH tanks are full (i.e. not enough spare capacity for flash flood protection). In Lancaster it can be seen that RWH tanks are empty for 3.7 months (May through to August) within scenario A and B. [N.B. In all cases data for scenarios A and B are identical as non-potable demands are equal, Table 3.] However, they are full for different time periods in all five scenarios; 5.5 months (mid October to end March) in A and B; 6.9 months for C; 11 months for D and 12 months for E. When considering the three other locations RWH tanks only ever fill in Scenario D and E, i.e. 12 months in each scenario for Birmingham and only 2 months and 7 months in Scenario D and E respectively for Barcelona. RWH tanks in Scenario C are empty for 4 months (April to July) in Birmingham; 4.5 months (mid-February to July) in Sweden and 8 months (January to August) in Spain. In scenarios A and B it can be seen that RWH tanks are empty year round in Birmingham, Barcelona and Malmö. Therefore an RWH solution poses least risk to NC3a in Lancaster because tanks are fullest year round in all scenarios, this is attributed to a much higher rainfall within this region. The opposite is true of Spain where most risk occurs. The least risk to NC3b occurs in Spain, followed by Sweden, Birmingham and then Lancaster. The risk in Lancaster is highest in winter months and lowest in summer months, where spare capacities of up to 2000 liters occur in scenarios A and B. The corresponding related outflows, from RWH tanks to the stormwater system, are also shown in Figure 4 (rhs). It can be seen how the adoption of RWH tanks significantly reduces stormwater outflows (per household) in all scenarios, in all locations, during the year. In Birmingham, Spain and Sweden stormwater outflows (from roofs) has deceased in Scenarios A, B and C, which could have implications for future infrastructure resilience (i.e. it may be oversized) or more simply in planning terms this would allow for more houses to be connected without modification. Scenario D is interesting because it is assumed to be the most sustainable solution in terms of reduced mains water demand and wastewater outflow, yet it offers least protection against fluvial floods and least reduced capacity requirements for stormwater infrastructure.

### 3.6 Stage 5 – Modification of solutions

In this stage solutions can be modified in order to change their performance and increase their resilience, e.g. if rainwater supplies are insuffiseint to meet demands it is not possible to increase rainfall. Although we might consider increasing collection areas. Table 5 shows a range of collection areas back-calculated from non-potable demands and expected rainfall. Scenario B (Barcelona) suggests a 89 m2 collection area (i.e. an additional 39 m2) should be sufficient to meet yearly non-potable water demands – 140 l/hh/day (Table 3). However, by also increasing the roof area above this value (Figure 5a), whilst maintaining at 1436 liter RWH tank (Table 4), we can see that more water is collected year round, i.e. a 110 m2 roof area leads to surplus water over 11.5 months (4.5 months more than when using a 90 m2 roof). If we then increase tank capacities (Figure 5b) in line with the 5 % annal rainfall design rule, surplus water will occur for 12 months with the 110 m2 collection area. Another alternative would be to use water collected from other rooftops (e.g. shopping centers, commercial or office roofs) where demand is much lower than potential rainfall supply. It is worth recognising that, under identical conditions, 80 % more rain can be harvested from pitched tiled roofs than from flat gravel roofs (Leggett et al., 2001); moreover rainwater availability per occupant will be higher in low occupancy dwellings with large roofs than high occupancy dwellings with small roofs (e.g. high rise buildings). Alternatively other solutions could be adopted (e.g. greywater recycling), however the benefits may not be identical and will have to be considered carefully and perhaps even traded-off.

| Location | Scenarios | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| Lancaster | 44 | 44 | 33 | 27 | 20 |
| Birmingham | 68 | 68 | 51 | 41 | 31 |
| Barcelona | 89 | **89** | 68 | 54 | 40 |
| Sweden | 72 | 72 | 55 | 44 | 33 |

Table 5. Collection areas back-calculated from non-potable demands and rainfall (unrestricted tank size).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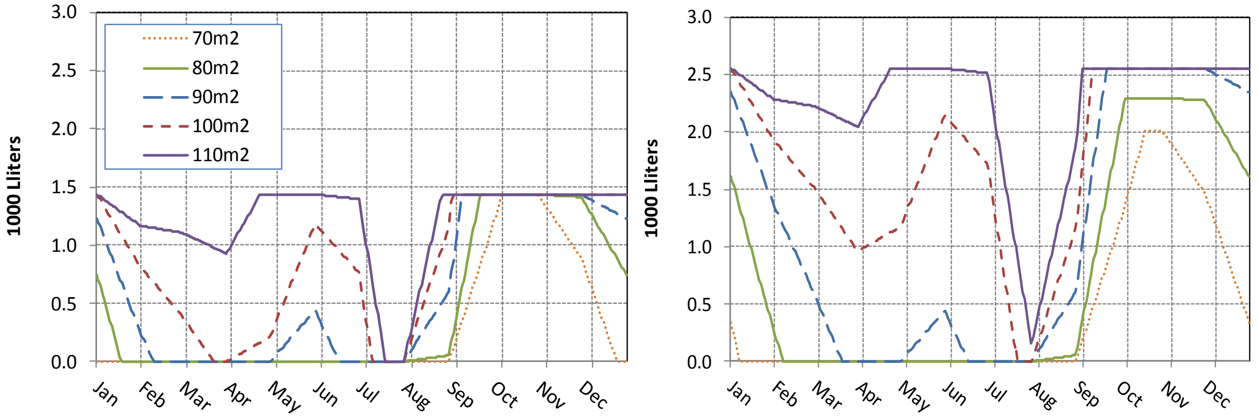


Fig 5. Influence of RWH roof size in Barcelona (a) 1436 liter RWH tank (b) RWH tanks sized for 5% annual rainfall

## 4 CONCLUSION

Through the use of an urban Futures methodology this paper has shown how it is possible to test the resilience of solutions that are being adopted today in the name of sustainability. By looking specifically at technology, user behavior and location through the use of a UF tool the close relationship between actions above ground and infrastructure requirements below ground can be better understood and tested in terms of sustainability performance and resilience provision. The methodology helps to raise questions that wouldn't normally be asked and enhances the solution that is put into place. The capabilities of the UF tool has far reaching implications (beyond what is presented within this paper) and can be used to inform decision-makers, planners and urban engineers alike. A future publication will describe the UF tool in detail.

## 5 ACKNOWLEDGEMENTS

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