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Strategic options for sustainable water management at new developments: the application of a simulation model to explore potential water savings

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Abstract Research on appropriate technologies and infrastructures to support water reuse has progressed rapidly over recent decades and there are now a wide range of source – treatment – reuse options for planners to choose from. Although the economics of water reuse schemes favours application to new developments rather than retrofit projects, there are few studies which have sought to address strategic option selection issues for large developments. The potential advantages of using treatment and reuse systems in new developments require an understanding of the relationships between a wide variety of social, environmental, technological, and operational factors. The operational effectiveness and economic efficiency of specific technology choices will vary as a function of network configuration, wastewater characteristics, how different technologies respond to dynamic loading (variability of feed strength and flow) and potential spiking, as well as equipment reliability, climate and household behaviour. Using a commercially available software package, the study reports the design and implementation of a low resolution simulation tool to explore sustainable water management options for a live case study site in the south of England (a peri-urban development of 4,500 new homes) with particular reference to opportunities for rainwater harvesting, and water reuse.
Keywords New developments; option evaluation; simulation model; sustainable water use

Introduction

At present, levels of new housing development in the UK are estimated to exceed 3.8 million homes by 2021. In the current climate of environmental awareness many developers are including energy and water efficient practices and sustainable principles in new build sites. This study reports on the strategic evaluation of sustainable water management options for one such new build site in the UK called The Wixams. The location of the development is some 5 km south of Bedford and 6 km north of Ampthill. The development area extends to some 384 hectares. The site forms part of the flat broad valley of the River Great Ouse, and the escarpment of the Greensand Ridge, an area of Great Landscape value lies to the south. Open farmland with well defined field boundaries are hedgerows clearly separates the site from the nearest settlements of Wilstead, Elstow, Kempston Hardwick, and Houghton Conquest. The proposed mixed-use development consists of 4,500 new homes in four villages, plus business, shops, schools and leisure facilities. Development at The Wixams will continue for between ten and fifteen years in a four phase program.

Strategic option evaluation

The first step in our analysis has been a brief review of the advantages and disadvantages of reuse, recycling and conservation practices, the availability and use of technical guidelines for each system and the potential for adoption of these practices within The Wixams peri-urban development (See Table 1).

Table 1 Review of strengths and weakness in recycling, rainwater and conservation options

Strategic option	Strengths	Weakness
Recycling	Continuous supply available. Variety of reuse options available.	Frequent maintenance of systems often required. Can be expensive to purchase and install (particularly if dual reticulation is required). Health impacts uncertain.
Rainwater	Lower treatment requirements. Cost effective technology.	Storage tank space requirements. Intermittent and unpredictable supply.
Conservation	Low cost. Not technology dependent.	Sustained impact often dependent on long term behavioural change. Incorrect installation of devices a problem.

Following this evaluation of the strengths and weaknesses of different options, we specified a simulation model which could be used to explore the water saving potential of each option.

Model design

The simulation model has been designed to support the following technology options; greywater reuse, grey and black water reuse, rainwater reuse (including stormwater options), and water conservation measures.

The appropriate scale of application was identified as being (at minimum) the village level. Supporting reasons for this choice are:

- Small scale reuse options have been demonstrated to have long financial payback times.
- Small scale reuse options raise problems from an ownership, maintenance and therefore health and safety perspective.
- The performance of small (meso) scale stormwater applications are poorly understood.
- Whilst conservation measures are typically implemented at a household level, the appropriate level of analysis in terms of water saving is at a much larger scale.

In terms of a model design and development agenda, the activity can be broken down into the following stages:

Stage 1 – Create a representation of the development and its water usage patterns under standard conditions and with no sustainable water management initiatives implemented (i.e. a base case). This will involve simulating gross flows of water of different qualities through the development from potable supply to wastewater discharge. Household and large non-domestic uses to be represented.

Stage 2 – Design and implement modifications to the model to support exploration of the sixteen scenarios itemised above in terms of water flows and savings.

Stage 3 – Associate (where possible) capex and opex costs to the different elements of water supply, reuse and discharge at the development. Capex values can be addressed outside of the model but Opex costs will be dependent on volumetric throughputs (could be treated internally or the data recorded and used to calculate costs externally).

Stage 4 – Run the model under the different scenarios, record and report on outputs.

The design template for the model stakeholders is shown in Figure 1. The core of the model is the representation of household water demand. Although the resolution of analysis is at a large scale, it will be useful to represent water use at the household level to facilitate future

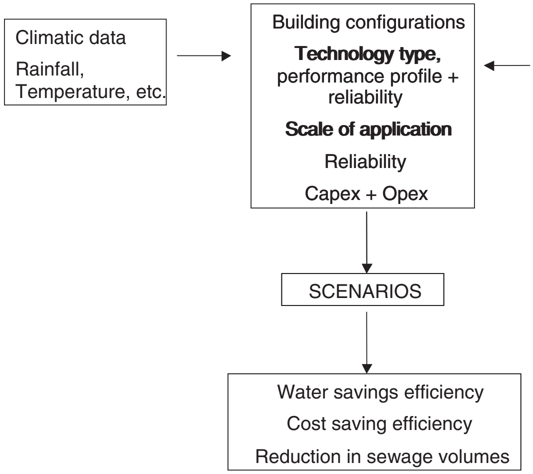

Figure 1 Model design template

development of the model's functionality. A picture of daily water demand is to be built up through consideration of individual water uses within a household.

Volumetric demand is modified by climatic variables (temperature and rainfall) based on empirical relationships. Empirical data is also available regarding the impact of different conservation measures on demand profiles. Individual household representations are combined to produce communities representative at the village and development scales. Initially this will entail all households being identical in their water use patterns. However, later versions could move on to consider variable water use patterns based on different socio-economic influences.

It should be remembered that the primary function of the model is to assess the water and financial savings which accrue from the various sustainable water management options. Consequently, consideration should be given to how such savings are going to be monitored and recorded in the model. At a minimum, simulation output data should be logged for:

- Volume of potable water supplied on a village or development scale
- Volume of water discharged from households
- Volumes of water treated at any treatment units
- Volumes of grey, black and rainwater supplied to households
- Water discharges out of the development
- Volumes of water saved through conservation measures

Water demand forecasting

Understanding potential future water demand changes is an essential component of strategically assessing the water supply options for The Wixams development and will form part of the model-based scenario exploration to be undertaken. It is important to realise that there can be no definitive conclusions drawn regarding future water demand (Downing *et al.*, 2003), only more or less reasoned and transparent investigations. The aim here is to be both reasoned and transparent. The basic principles behind the water utilisation model are to determine:

1. For each identified water use (or micro-component) the per capita consumption (PCC) in l/h/day.
2. The total population (occupancy) of each village on each day based on UK Government statistical information about the average number of holidays taken by people in East Anglia during different months of the year.

3. The total volume of water used for each water use as a simple product of total population and PCC.

Each micro-component is then structurally associated in the model with a particular grade of water to be used (potable, recycled or rainwater) and also with a disposal option (to main sewer or to effluent treatment). The total amount of water of each grade demanded is then the simple sum of all micro-components structurally linked to each grade. Different scenarios will explore the impact of linking micro-components to different grades of water (e.g. supplying WCs with recycled instead of potable water) and also to different disposal routes (e.g. washing machine effluent to grey water treatment rather than main sewer).

So how best to determine PCC for each domestic micro-component for the present and the future? A simple solution would be to use existing data on average PCC. These could then be manually changed by the user between runs to explore different utilisation scenarios representing possible future water demand or simply held constant. A more complicated solution would be to link PCC for each micro-component directly to climate variables like precipitation or temperature or other socio-economic factors. Alternatively, existing future water demand scenario forecasts could be directly used within the model, either automatically (phased in as functions of time from equations or data files) or manually. The reader should note that using a micro-component approach is recommended as "best practice" to forecasting domestic water demand by the UK Environment Agency (Environment Agency, 2001).

The EA's scenarios for all sectors are based upon the DTI's Foresight programme, extended and interpreted to forecast water demand (Environment Agency, 2001). There are 4 scenarios organised along axes representing social values (consumerism vs. community) and system of governance (regionalisation vs. globalisation):

- *Alpha* scenario: consumerism and regionalisation.
- *Beta* scenario: consumerism and globalisation.
- *Gamma* scenario: community and globalisation.
- *Delta* scenario: community and regionalisation.

Each scenario represents a plausible and possible future, useful for strategic planning and management. The scenarios look at the domestic sector in terms of metering and water regulations (policy drivers), white goods (technology driver), type and pattern of personal washing and garden watering (behavioural drivers) and personal affluence (economic driver). Briefly, for the domestic sector the EA scenarios infer:

- *Alpha:* growth in affluence declines, limited availability / uptake of water efficient goods.
- *Beta:* high economic growth, technological improvements / uptake, "discretionary" uses of water increase (power showers, hoses etc.).
- *Gamma:* strict demand management regulation, highly efficient technologies with high consumer take-up due to levels of affluence.
- *Delta:* consumer attitudes shift, fall in "discretionary" uses, efficient technology uptake.

To tie in with the microcomponent based approach being taken we modify our current PCC data using the results detailed in Environment Agency (2001). However, not all microcomponents are "active" all of the year (e.g. gardening is largely constrained to summer) and not all microcomponents remain at the same demand level for the whole of the year (e.g. bathing may increase in summer due to the hotter weather). We need to switch some microcomponents on and off and change the demand levels of others depending on the time of the year. Which ones and how? Switching demand on and off or varying levels within a year can be viewed as a result of climatic changes such as lowering of precipitation and increasing of temperature during summer leading to a decrease in soil moisture levels and the subsequent increased need to water garden plants. Indeed Herrington (1996) suggests that "variations in peak factors over time . . . are largely associated with climate". We shall therefore look for climate sensitivity in demand as a means of determining which microcomponents to change and how.

Downing *et al.* (2003) identify four climate sensitive (CS) demand microcomponents; gardening, bathing (incl. showering), car washing, and miscellaneous (we will interpret this as our "kitchen sink" microcomponent – drinking, cooking from kitchen tap etc.). CS microcomponents may change value within a year due to climatic variation and also potentially change value over many years due to the effects of climate change along with technological, behavioural, policy or economic factors. We will assume that these three CS microcomponents are the only ones to vary in demand across a year. This defines our list of constant within year, or non-climate sensitive (NCS) demand microcomponents as: Clothes washing, Dish washing, and Toilet flushing. NCS microcomponents may change value over the course of a number of years due to technological, behavioural, policy or economic factors but they will not change value within a year or across many years as a result of climatic variation or change.

We will now detail the demand modelling approach to be taken for each CS microcomponent in turn, taking garden watering first. Both Herrington (1996) and the Environment Agency (2001) treat garden watering as an activity largely restricted to the months of May to August, except in dry years when the period of watering may extend to cover April to September. We will take the least conservative approach and assume that gardens are watered between the months of April and September every year. However we shall assume that the demand during April and September is 50% of the demand from May to August to represent a phasing in of watering activity during the year and to comply with the conclusions of Herrington (1996) that soil moisture deficit, as a causal factor behind garden water demand, becomes more significant from May onwards with small effects by September. To model these changes in demand we will assume a PCC of 0 Ml/day for the "winter" months October to March and then assign the "baseline" current PCC data plus the annual increment imposed by the Environment Agency (2001) scenarios for the "summer" months April to September, taking into account the 50% reduction for April and September.

The next microcomponent is personal washing. Herrington (1996) determined for an area supplied by Three Valleys Water (and therefore climatically not too dissimilar to The Wixams) that average weekly domestic PWS demand for the period from 1981–1989 was higher by about 6% over the summer months of April to September compared to the winter months (Table 2). Given the lack of other data and the uncertainties involved we will take this result as a reasonable "ball park" assumption and apportion the demand for personal washing within each year accordingly. Similarly, given the lack of data on car washing and "kitchen sink" use we will apportion demand for these microcomponents in the same manner, using the 6% summer month increase figure.

In terms of the model we keep the same total annual demand for both of garden watering and car washing microcomponents by subtracting 3% from baseline PCC for the winter months whilst adding 3% to the baseline PCC for the summer months. This gives a 6% difference between summer and winter demand and maintains overall demand levels. Scenario caused annual change will be calculated using the unaltered "baseline" PCC figure for each microcomponent and applied using the ± 3% rule. Table 2 provides demand details for a model run with no climate change for each domestic microcomponent (% change at the end of a 20 year time horizon, ~ equating to the EA's 2025 scenario horizon along with appropriate annual increment).

Results

The modelling approach used enables literally hundreds of variables to be recorded and saved in tabular format. Micro-component water flows at household, village or develop-

Table 2 Percentage change in domestic microcomponent demand over a 20 year simulation run

Micro-component	Alpha % Δ	Beta % Δ	Gamma % Δ	Delta % Δ
Kitchen sink	+41.7	+24.6	−17.9	−17.2
Personal hygiene	+77.4	+63.1	−24.5	−7.8
Clothes washing	−5.4	−42	−50.5	−50.4
Dish washing	−2.2	−14.4	−15.7	−13
Toilet flushing	−21.4	−27.4	−42.9	−34.5
Gardens	+83	+77.7	+12.9	−72.2
Car washing	+58	+47.8	−11.9	−46.3

ment level can be monitored, as can details of the relative proportions of potable, recycled and rainwater used for each household and commercial water use. Each of the 44 simulations was run over a twenty year period.

Figure 2 shows the total potable water supplied to the development under each of the 44 scenarios. The pattern of results for this, as well as for all other output variables, needs to be understood in the context of the pattern of scenarios. For example, the influence of the four EA scenarios can be clearly discerned as the high values for potable supply occur in a four-year cycle (Scenarios 1, 5, 9 etc.) – conforming to the EA Alpha scenario. The lowest potable supply volumes correspond to Scenarios 30–36. These scenarios represent stormwater and wastewater reuse for domestic and non-domestic uses at the development scale.

As noted in the sections on water recycling and rainwater reuse, one of the central design issues with theses types of system is sizing. One way in which the simulation model can support assessment of capacity requirements is by indicating the maximum and minimum demand for sub-potable waters across the timescale of interest. Figure 3 depicts the maximum and minimum daily recycled water volumes demanded under those scenarios which call for high levels of water recycling or stormwater reuse.

Conclusions

The model described above is clearly capable of generating an extensive set of data regarding water flows through the proposed development. Specifically, it can be used to investigate the water saving and cost implications of supplying non-potable demand nodes with either recycled greywater or rainwater. Simulations are currently being run to both

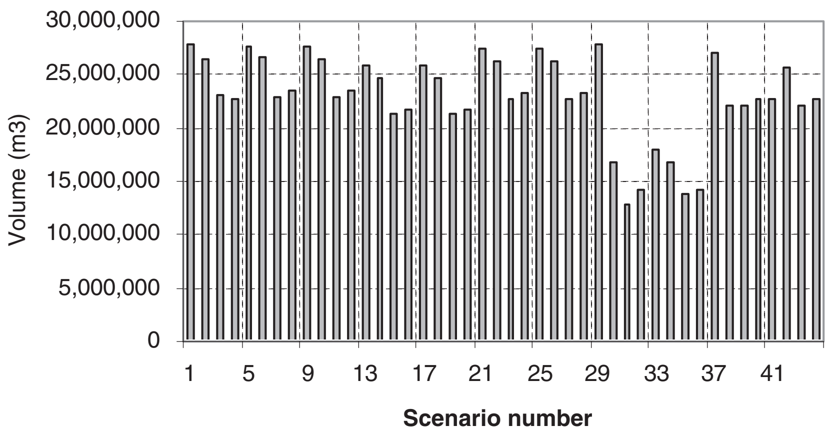

Figure 2 Total potable water supplied to the development over 20 years

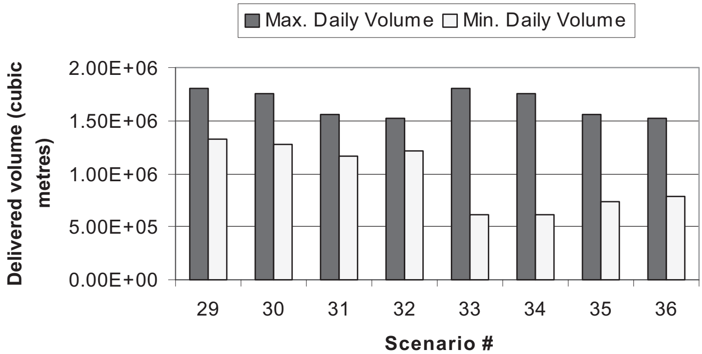

Figure 3 Maximum and minimum daily volumetric supply of non-potable water for selected scenarios

validate the structure and verify the performance of the model, and quantify the water and cost saving achievable with different reuse/rainwater options under different sets of assumptions regarding system scale and climate change. Our work to date suggests that;

- Commercially available simulation tools can be readily used to represent gross water flows through a new development and explore different water management options.
- Future demand profiles will strongly influence the financial and water saving performance of different management strategies and therefore, micro-component water demand prediction is a key element of strategic option assessment.

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