

8.0 Conclusions and Recommendations for Further Work

The first section of this chapter presents a synopsis and the main conclusions that relate to the rainwater harvesting (RWH) literature review (chapter two) and state of the art (chapters three and four). Section 8.2 briefly discusses the creation of the thesis RWH modelling tool. Sections 8.3 and 8.4 present the main conclusions from the modelling studies that were conducted for a range of domestic RWH systems and a school case study. The primary contributions to knowledge are summarised in section 8.5. Finally, recommendations for further work are presented in section 8.6.

8.1 Rainwater harvesting literature review and state of the art

8.1.1 Rainwater harvesting literature review

Chapter two was a general literature review covering the key aspects of contemporary RWH. Traditionally, urban areas in developed countries have been supplied with cheap, safe and abundant water via the provision of large-scale centralised water treatment and distribution systems (mains supply). However, there is growing concern that the traditional approaches may not be sustainable due to increased pressures from population growth, climate change and, in some areas, lack of additional developable resources. RWH is one demand management measure that has the potential to reduce reliance on mains supply and is suited to non-potable uses such as WC flushing, garden irrigation and laundry cleaning (washing machines). These low-risk uses generally have high public acceptability, although uptake of RWH has still been relatively slow in the UK. In metered properties there is the potential to save

money by substituting mains water for harvested rainwater and studies have shown that the public consider financial performance to be an important factor. RWH could be suitable for new-build developments, particularly domestic dwellings. However, there is currently limited information regarding the likely level of RWH system performance. This is especially true with regards to their long-term financial effectiveness compared to relying solely on mains supply. If RWH is to become more widespread in the UK then it would be beneficial to have a greater understanding of the financial implications and monetary saving potential.

The aims and objectives of this thesis were therefore to:

- Review the literature and determine the state of the art with regards to contemporary RWH in the UK, principally in relation to the prediction of financial performance, and to identify gaps in existing knowledge.
- Develop a computer-based modelling tool for the hydrological and financial assessment of RWH systems for non-potable uses at the single-building scale.
- Gather relevant data with which to populate the new model.
- Use the model to conduct a detailed financial analysis of a range of theoretical but realistic RWH systems for new-build developments, with an emphasis on domestic installations. A system designed for a new communal (school) building was also assessed.
- Evaluate the model outputs and draw a number of conclusions regarding the long-term financial performance and viability of RWH systems for new-build developments (domestic dwellings and communal buildings).

8.1.2 State of the art: methods of modelling the hydrological performance of rainwater harvesting systems

In chapter three a range of key RWH system components were identified that required inclusion in the thesis model. These were rainfall, catchment surface, first-flush diverter, coarse filter, pump, UV unit, potable (mains) water supply and sewerage system (volumes to and from), storage tank and non-potable supply and demand. Methods for modelling each of these were discussed and suitable approaches selected.

With regards to the storage tank, two general categories of modelling approach were identified: Moran related methods and critical period methods, with the former being subdivided into two further categories: mass curve analysis and behavioural analysis. The academic literature showed that use of behavioural analysis is widespread and this approach was also deemed to be the optimal choice for the thesis model. Two fundamental behavioural algorithms were identified: Yield After Spillage (YAS) in which the order of operations is determine yield, inflow, overflow and extract yield; and Yield Before Spillage (YBS) is which the order of operations is inflow, determine yield, extract yield and overflow. A generalised form of the YAS/YBS algorithm exists. This uses a storage operating parameter θ to determine the extent to which the algorithm reflects the YAS or YBS variants. If $\theta = 0$ the form is YAS whereas if $\theta = 1$ then form is YBS. For values between 0 and 1 the algorithm reflects both YAS and YBS algorithms to varying degrees. The generalised YAS/YBS operating algorithm was implemented in the thesis model with θ set to zero (YAS).

Behavioural analysis operates in discrete timesteps and existing research has used periods of minutes, days, weeks and months. A timestep of one day was selected for implementation in the thesis model and this choice was discussed and justified.

A method for estimating non-potable demand in new-build houses was presented. This was based on a micro-component approach, with the micro-components consisting of WC, washing machine and garden irrigation. The effects of climate change on the latter component were taken into account in accordance with the latest UKCIP climate change scenario research.

8.1.3 State of the art: financial assessment of rainwater harvesting systems

In chapter four it was stated that the intention of the thesis was to explicitly consider only the tangible financial aspects of RWH. It was acknowledged that intangibles also exist (externalities), such as environmental and social costs/benefits. However, consideration of these aspects was outside the scope of the thesis.

A review of the academic literature was conducted in order to determine the state of the art with regards to the financial assessment of RWH systems. It was found that studies to date had concentrated predominantly on water saving reliability, either ignoring financial aspects entirely or assessing them in an ad-hoc manner with limited scope and detail. These criticisms were found to be especially valid with regards to UK-centric studies. This discovery was a major

justification of the need for this research project. Financial performance was most commonly assessed by predicting the cost of supplying water from the RWH system and then comparing this to the cost of supplying the equivalent volume of water from the mains system.

A range of financial assessment techniques applicable to the water sector were identified, with a view to determining the most appropriate for the financial assessment of RWH systems. The identified approaches included cost benefit analysis, social cost benefit analysis, cost effectiveness analysis, net present value, internal rate of return, payback period, total resource cost test, average incremental costs and whole life costing.

Whole life costing (WLC) was selected as the most appropriate approach and this choice was discussed and justified. The principles, advantages and limitations of a WLC approach were discussed. Data requirements were identified. In broad terms these consisted of asset design life, capital (purchase and installation) costs, operation and maintenance costs, monitoring costs, risk costs, environmental costs, disruption costs, disposal costs, residual costs and the discount rate and discount period. Not all of these were directly relevant to the RWH systems assessed in the thesis. The decision to exclude some items was discussed and justified. For those items that were considered, a wide range of data was collected in order to support the WLC analysis. This data was presented and discussed.

Finally, the hydrological design and financial assessment methods commonly employed by UK RWH system suppliers were investigated. This was only prudent since the majority of system sales in the UK occur via a relatively small (but growing) number of private sector companies. The use of “rule-of-thumb” approaches was found to be widespread. Examination of these methods revealed that the hydrological analysis tended to be rather basic, although they generally did include most or all of the previously noted key components. Assessment of financial performance was somewhat worse with many cost items missing from the analysis altogether, particularly maintenance requirements. Financial assessment techniques were often incorrectly applied or not at all, e.g. discounting methods. It was proposed that the results generated by the “rule-of-thumb” methods be compared with those produced by the more rigorous thesis model.

8.2 Rainwater harvesting model development

Chapter five brought together the concepts and information gathered in the previous chapters in the creation of a new spreadsheet-based modelling tool. The model is deterministic in nature and based on a daily timestep. Water saving efficiency is predicted using the mass-balance transfer principle. The YAS storage tank operating rule was implemented via the generalised YAS/YBS algorithm ($\theta = 0$). The primary functions of the model are the hydrological and whole life cost assessment of RWH systems at the single building scale. Several other financial metrics were considered to provide useful information and so these were also included. These were the calculation of average incremental costs (AICs) and the payback period.

8.3 Assessment of rainwater harvesting systems for new-build domestic dwellings

Chapter six investigated the use of domestic RWH systems for new-build houses. Both the hydrological and financial performance were investigated although the focus was on the latter. The main purpose of this study was to provide information on the long-term financial effectiveness of domestic RWH systems at the single building scale. This was achieved primarily through estimation of RWH system WLCs and RWH system savings compared to relying solely on mains-only supply. The study region was West Yorkshire and so metered mains water costs relate to Yorkshire Water (YW).

A wide range of different RWH system configurations and assessment criteria were modelled in order to provide a comprehensive set of results. Sixteen tank sizes (1.2-15.0m³), three different water use scenarios (WC flushing only; WC flushing and garden irrigation; WC flushing, garden irrigation and washing machine), four discount rates (3.5%, 5%, 10% and 15%), four discount periods (5, 10, 25 and 50 years) and household occupancies in the range of 1-5 were assessed. The use of UV units was not considered since research has shown these are not necessary in well designed and operated non-potable domestic systems. The total number of permutations was therefore 3,840 and all of these were simulated. The results were compiled and analysed in order to provide information on the predicted hydrological and financial performance of domestic RWH systems. The main conclusions from these studies are given below.

Sensitivity analysis: percentage changes in RWH system savings, a key financial metric, were selected as the means for judging model sensitivity. Savings were calculated by subtracting the RWH system WLC from the equivalent mains-only system WLC. Variations in a number of key parameters were assessed. These were the daily rainfall depth, capital costs, maintenance costs, mains water supply and sewerage charges, roof area, discount rate and discount period. The effect of varying the storage operating parameter θ between 0 (YAS) and 1 (YBS) was also investigated.

It was found that the RWH system savings were highly sensitive to changes in capital costs. For high discount rates and short discount periods the sensitivity to changes in the other parameters was small. At low discount rates and longer discount periods sensitivity to the other parameters increased but was still greatest for the capital costs in all cases. Varying θ between 0 and 1 (YAS/YBS) resulted in only a small change in the predicted savings, in the majority of cases by only a fraction of a percent. This validated the decision to implement the YAS algorithm and also demonstrated that selection of the YBS variant would also have been acceptable.

Water saving reliability: for each modelled scenario it was theoretically possible to meet 100% of the selected non-potable demand. However, in many cases unfeasibly large tank sizes would be required in order to achieve this, in some instances requiring hundreds of cubic metres of storage capacity. For low water use scenarios (WC flushing only) meeting about 90% of the non-potable demand was possible with reasonable tank sizes. For higher water use

scenarios (WC flushing, garden irrigation and washing machine) meeting up to 50% of the non-potable demand was found to be realistic. With regards to total household demand, potentially about 55% can be met by harvested rainwater. However, when simulations were run using a sensible range of tank sizes it was found that a more realistic figure was between 15-28% of the total demand.

Whole life costs: in all instances the WLCs of the simulated RWH systems were found to be significantly higher than the WLCs of the equivalent mains-only systems, often by several thousand pounds. That is, in all cases installing a RWH system proved to be ultimately more expensive than relying solely on mains-only supply. The simulated scenarios were designed to reflect a wide range of *plausible* and *typical* new-build domestic situations in which contemporary RWH systems could be used. The results indicated that, at current capital cost levels, it is highly unlikely that domestic RWH systems are able to confer financial savings under most circumstances. The primary reason for the generally poor financial performance was the high capital costs. It is suggested that research aimed at reducing the capital costs (both system purchase and installation) would be highly beneficial in improving the financial effectiveness of domestic RWH systems.

Analysis of capital cost recovery revealed that the average value for the sixteen tank sizes assessed was in the range of only 0.2-3.8%, i.e. the ultimate financial losses were approximately equal to the capital cost expenditure. The best advice would therefore be not to install any RWH system if financial savings are an important criteria. However, if a system is to be installed then, in order to

minimise the likely financial losses, the system with the lowest capital costs should be selected. Smaller rainwater tanks are generally cheaper than the larger varieties and so this would imply the selection of smaller tanks.

It was also noted that, due to the effects of discounting future cash flows, repayment of the capital costs was not linear and tended to reduce in magnitude over time. This led to the observation that RWH systems have a finite window of opportunity to repay the capital expenditure, and the higher the discount rate the shorter this period will be. Further, long payback periods reported in the literature, for example 55 and 267 years (Brewer *et al*, 2001), seem unlikely given the attenuating effects of discounting.

Direction of RWH system savings: Of the 3,840 domestic simulations conducted it was found that 907 (24%) showed continuing monetary losses during the operational phase, i.e. instead of beginning to pay back the initial capital investment they were instead accruing further losses. These findings were associated with systems that had low occupancy rates, low water uses and low discount rates but higher discount periods. The reason for the continuing losses was due to the maintenance costs which, for systems with the aforementioned characteristics, exceeded the average annual reductions in water bills.

This highlights the importance of fully accounting for all likely maintenance requirements, which the existing research does not do. It also raises the point that even for systems where the user does not pay the capital costs, e.g. due to capital cost subsidies or grants, it is still possible to lose money. Therefore it is

recommended that if subsidies or grants were to become available for domestic systems then preference should be given to dwellings with high occupancy rates and high water uses.

Average incremental costs: AICs (£/m³ of water supplied) were calculated for each of the simulated domestic RWH and equivalent mains-only systems. It was found that in every instance the RWH AICs exceeded those of the mains-only AICs. The AIC ratio was defined as the RWH AIC divided by the equivalent mains-only AIC. These ratios were found to be in range of 1.48 to 59.04. That is, on a cost per unit basis the water supplied from the RWH systems was between 1.48 and 59.04 times more expensive than that from the mains-only systems. The average AIC ratio was 7.58. It was concluded that, using average incremental costs as the financial metric, RWH systems are not cost effective compared to mains supply systems.

The predicted RWH AICs were compared to those presented in the literature for a range of alternative water demand management measures. These consisted of various types of low flush WCs (including displacement devices), different types of showers, metering policies, greywater systems, rainwater butts, targeted sprinkler use, water audits and the replacement of washing machines with more efficient versions. AIC values for these measures were in the range of £0.00-7.63/m³ with an average of £1.74/m³. Out of the 3,840 RWH systems assessed, 85 had AICs lower than the aforementioned average value. Each of these was associated with a high level of water use, high occupancies, long discount periods and high discount rates. The results indicated that, using an

AIC metric, RWH systems could be financially competitive with some water demand management measures. However, this was true only when using a fairly restricted combination of assessment criteria. It is concluded that other water demand management measures should be implemented before consideration is given to RWH systems.

Contribution of key cost elements to RWH system WLC: the relative contribution to the RWH WLCs of various key cost components was determined for a typical domestic system. The cost elements consisted of capital, maintenance, supply standing charge, sewerage standing charge, mains top-up and pump operating (electricity) costs. A range of discount rates, discount periods and occupancy rates was assessed. The range and average results (in brackets) were as follows: capital cost 34-85% (70%), maintenance costs 0-31% (12%), supply standing charge 1-7% (3%), sewerage standing charge 2-7% (3%), mains top-up charge 3-33% (13%) and pump operating (electricity) cost 0.1-0.6% (0.2%). The capital costs were the major cost item in most cases, particularly when using high discount rates and short discount periods, and the largest single contributor to WLCs in all cases. Maintenance costs and mains top-up in some instances accounted for a considerable portion of the WLCs, particularly when low discount rates and long discount periods were used. The contribution from the remaining costs was low in all cases, especially with regards to pump operating (electricity) costs which were minimal.

Effect of changing household occupancy rate RWH system savings: analysing the effect of varying the household occupancy rate for a range of system

conditions and assessment criteria it was clear that in all cases increasing the occupancy rate led to an improvement in the predicted RWH system savings. The rate of increase was not the same across the range of criteria assessed and was greater for lower discount rates and higher discount periods. The average rate of improvement between occupancies 1 and 5 was in the range of 6.4-25.1% with the higher rate corresponding to increases in savings of about £1,300. Whilst this was a significant improvement there was still an overall financial loss. From this study it was concluded that increasing the occupancy rate leads to an improvement in RWH system savings which can in some cases be significant, that the rate of improvement is greater at lower discount rates and higher discount periods, and that although some improvement did occur it was insufficient to enable domestic RWH systems to compete financially with mains-only supply.

Mains supply and sewerage charges: the sensitivity analysis showed that increasing the mains supply and sewerage unit charges led to a linear improvement in RWH system savings. It therefore followed that some value must exist for these parameters at which RWH systems can be financially viable compared to the equivalent mains-only systems. Modelling a typical domestic system under a range of criteria it was found that, using a YW unit cost of £1.13/m³ for comparison, for break-even to occur mains water charges would have to increase by up to 18.4 times their current rate (£20.82/m³), 8.9 times on average (£10.00) and by at least 3.8 times (£3.80/m³). Historic water price data shows that YW metered mains costs have risen by approximately 3% per year compared to their value at the time of privatisation. Even assuming *compound*

growth of 3% per year, a value of £3.80/m³ would not be reached until approximately 2050. An increase in the cost of mains water alone would therefore appear to be insufficient to render domestic RWH systems financially viable in the near future.

Investigation of commonly used design and assessment methods: a range of 'rule-of-thumb' (ROT) methodologies commonly used by the UK private sector for the design and financial assessment of domestic RWH systems were investigated. The results from these investigations were compared to those from the more rigorous thesis model. It was found that the ROT methods:

- Do not realistically model tank behaviour and significantly overestimate the volume of harvested rainwater that can be supplied.
- Recommend the use of tank sizes outside of the "optimum" hydrological and financial performance range.
- Do not adequately account for likely operation and maintenance costs, often assuming that these will be low or even zero. Consequently the monetary benefits are greatly exaggerated. Financial gains are predicted where significant financial losses are more likely.

Based on these findings it was recommended that the use of ROT methods for the design and financial assessment of domestic RWH systems should be avoided, particularly in the latter case as the predicted financial performance is unrealistically optimistic. Whenever possible a more thorough and scientific approach should be taken.

8.4 Rainwater harvesting systems for communal buildings

Chapter seven reported the results from the hydrological and financial assessment of a RWH system for a proposed new-build school. In brief, the relevant characteristics of the school and RWH system were as follows: 640 pupils, non-potable water uses WC and urinal flushing with a yearly water demand of 1,547m³, operational life of school 50 years, roof plan area 1,845m², selected rainwater tank size 54m³, system to include UV unit. A range of different discount rates were used in the assessment (3.5%, 5%, 10% and 15%).

RWH system savings and AIC results: RWH system savings were predicted in the range of £24,015 to -£4,917 for the range of discount rates assessed. The wide range of results, some showing a financial gain and others a financial loss, highlighted the influence of the selected discount rate. Lower rates were associated with greater savings. AICs and AIC ratios were also calculated for the same discount rates. Ratios were in the range of 0.77-1.17, demonstrating that the school RWH system was able to deliver water at a cheaper rate than mains supply in some cases. AIC ratios were more favourable towards the RWH system at lower discount rates, again highlighting the influence of the selected rate.

Detailed breakdown of costs: the relative contribution to system WLCs of the capital, maintenance, UV unit operating, pump operating and mains top-up costs were determined. A variety of discount rates were assessed. The range and average results (in brackets) were as follows: capital 21-50% (34%),

maintenance 13-21% (17%), UV unit operating 1.2-2.1% (1.7%), pump operating 0.7-1.2% (1.0%) and mains top-up 35-55% (46%). Mains top-up, capital and maintenance costs accounted for the majority of the WLCs in all cases. UV unit and pump operating costs were only a small part of the WLCs.

The relative contribution of each cost element was found to vary with different discount rates. Higher rates placed more emphasis on the capital costs whilst lower rates gave more emphasis to the other cost components. Lower discount rates had the effect of increasing the present value of future expenditures and thus increasing their percentage share of the WLCs.

Sensitivity analysis: variations in RWH system savings to changes in a number of key parameters were assessed. These parameters were the daily rainfall depth, capital cost, maintenance costs, mains water supply and sewerage charges, roof area, discount period and water demand. The effect of varying the storage operating parameter θ between 0 (YAS) and 1 (YBS) in conjunction with different discount rates was also investigated.

In all cases RWH system savings were most sensitive to changes in mains supply and sewerage charges. Results for the other parameters varied but system savings showed moderate to high sensitivity in most instances. Savings showed greater sensitivity to capital costs at higher discount rates. For the remaining parameters the sensitivity remained relatively constant for different discount rates. Given the level of observed sensitivity to changes in the key parameters, and the level of uncertainty surrounding the future values of those

parameters, accurately predicting the long-term financial performance of RWH systems such as the one used in the school case study would seem problematic.

Varying θ between 0 and 1 (YAS/YBS) resulted in changes in savings of between 6.3-8.4% for the lower discount rates, a difference of between £413 and £1,518 in system savings. For the higher discount rate of 15% the difference in savings between YAS and YBS was 204%. This large percentage change was due to the predicted savings being in the order of only a few hundred pounds (over 50 years) and so even relatively small monetary changes led to correspondingly large percentage changes. Considering these findings it can be stated that in this instance the use of YAS in preference to YBS was not fully vindicated. However, the difference in savings between the two approaches was not excessively large in monetary terms and so the choice of tank operating algorithm is unlikely to make a critical difference to the predicted financial performance.

Comparison of thesis model results with RWH system supplier's method: a comparative study was conducted between the predicted RWH system performance using the supplier's own method and the thesis model. It was concluded that the supplier's method:

- Did not realistically model tank behaviour and overestimated the volume of harvested rainwater that could theoretically be supplied.
- Did not adequately account for likely operation and maintenance costs.

- Significantly overestimated the magnitude of financial savings that were ultimately achievable, primarily because no discounting techniques were employed in order to adjust future cash flows to their present value.

Based on these limitations it was advised that claims regarding both the water saving reliability and financial benefits be treated with caution if they been derived using similar methods. It was strongly recommended that a more detailed and realistic approach be used whenever possible.

8.5 Contributions to knowledge

The primary contributions of this thesis to the existing knowledge base are summarised below. They have been divided into three sections: general contributions to the field, contributions relating to domestic RWH systems and contributions relating to the school case study, which can be considered as an example of a commercial RWH system.

8.5.1 General contributions to the field

With regards to general contributions to the field, this thesis:

- Determined the state of the art with regards to the assessment of both hydrological and financial performance of contemporary RWH systems at the single building scale for new-build developments.
- Critiqued current approaches to the financial assessment of RWH systems, identified shortcomings and gaps in knowledge.
- Explained and justified how whole life costing could be used as the basis for a more rigorous approach to the financial assessment of RWH

systems. A diverse range of costing data with which to support this assessment was gathered, collated and presented.

- Brought together existing hydrological modelling techniques with the proposed WLC approach in the creation of a new modelling tool. In terms of modelling the financial performance of RWH systems at the single building scale, this tool is more comprehensive and more inclusive than any existing approach.

8.5.2 Domestic RWH systems: contributions to knowledge

With regards to contributions to the field of domestic rainwater harvesting for new-build houses, this thesis:

- Provided a rigorous consideration of the cost issues surrounding the use of domestic RWH systems, and thoroughly investigated those costs.
- Identified the key parameters that determine RWH WLC performance and corresponding RWH system savings, including how WLC performance varies in response to changes in these parameters.
- Conducted assessments on a wide range of plausible systems and provided information on probable hydrological and financial performance.

For the hydrological performance it was found that current assumptions with regards to the level of household demand that can be met with harvested water are overly optimistic. With regards to the financial performance it was found that domestic RWH systems are not cost effective under the range of operating conditions likely to be encountered in practice. It was concluded that domestic systems ultimately result in a

financial loss and that this will be approximately equal in magnitude to the initial capital cost expenditure.

- Compared the cost effectiveness of RWH to alternative demand management measures and in most cases found that the latter were the better investment option. It was recommended that alternative demand management measures should be considered before RWH.
- Validated the use of the YAS tank operating algorithm as a suitable approach in a hybrid hydrological/financial assessment model.
- Investigated a number of commonly employed “rule-of-thumb” approaches for the design and financial assessment of domestic RWH systems. It was found that these significantly overestimate both the water saving reliability and monetary saving potential. A continued reliance on these methods was not recommended.

8.5.3 Communal RWH systems: contributions to knowledge

With regards to contributions to the field of commercial rainwater harvesting for new-build developments, this thesis:

- Identified the key cost elements for the case study RWH system, many of which have been omitted in existing studies of similar systems.
- Conducted a detailed analysis of the case study system, identifying the key factors that determine the RWH WLC performance and the corresponding RWH system savings, including how performance varies in response to changes in these parameters.
- Determined that financial savings are possible for such systems and that, under favourable circumstances, these can be quite substantial.

- Investigated a RWH system supplier's methodology for the design and financial assessment of commercial systems. The supplier's approach was found to overestimate the water saving reliability, and to significantly overestimate the predicted financial savings.

8.6 Recommendations for further work

During the course of this project a number of potential avenues for future research have presented themselves. These include:

- Consideration of a wider range of domestic systems. These could include less typical houses, such as those with large roofs, higher occupancies and greater water uses (including potable water applications). Systems that use one tank to supply multiple properties also exist. It is possible that the per dwelling capital costs of these systems are lower than those at the single-building scale. The financial implications of this would be worth investigating.
- Assessment of systems in different parts of the country could be beneficial and would allow for the impacts of regional climate variations and different water utility costs to be investigated. This could culminate in a map of the UK showing the predicted water saving reliability and financial performance of domestic RWH systems at different locations.
- Consideration of a wider range of commercial systems. These could include other school systems as well as those for different building types such as offices, factories, warehouses, airports and so forth.

- Investigate further the effects of climate change on the garden watering component. In this thesis only one UKCIP climate change scenario was considered (medium-high emissions) out of four available options.
- Monitoring of in-situ RWH systems in order to gather performance data with which to further validate the thesis model and to help identify areas of weakness.
- Collection of more accurate and site-specific capital cost data, particularly for domestic systems as this was the overwhelming factor in determining RWH system savings (or lack thereof).
- Collection of more data regarding the operating/maintenance phase, particularly maintenance requirements and costs, plus a better understanding of likely component services lives.
- Analysis at different scales. This study only considered RWH at the single building scale. However, implementation at development and regional scales is also possible. It would be informative to know if the financial limitations of domestic RWH systems could be offset, and if so to what extent. For instance, in new developments could the downstream drainage infrastructure be downsized, or could the need for further mains supply infrastructure be offset or negated altogether? What would the financial implications be if this were possible?
- The selection of the YAS algorithm for the school case study was not fully vindicated and the YBS variant predicted somewhat different results, although the difference was not considered critical. However, further investigation to determine which of these two approaches yields the more accurate results is recommended.

- The current analysis only considered monetary costs and was therefore classed as a financial assessment. An economic assessment could be performed which would also include relevant environmental and social costs. This could be conducted using, for example, a multi-criteria assessment framework such as that described by Ashley *et al* (2001).
- The whole life cost assessments conducted as part of this thesis only considered the costs from the viewpoint of one stakeholder at a time, and assumed that the stakeholder would be solely responsible for all costs incurred during the operational lifetime of the RWH system. Further, potential cost savings were limited to the amount of money that could be saved by substituting metered mains water for harvested rainwater. Future analysis could include a more complex arrangement of stakeholders and financial arrangements. For instance, a water utility may be considering paying for or subsidising the installation of RWH systems if this meant that they could then offset the need to build new water supply infrastructure such as reservoirs. RWH system users would then be responsible only for the operation and maintenance costs of the systems. Arrangements in which different stakeholders are responsible for different aspects of RWH systems, and where various stakeholder groups may have different objectives, would be worth investigating in more detail.