Rainwater harvesting in the UK: a strategic framework to enable transition from novel to mainstream

Submitted by

Sarah Louise Ward

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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ABSTRACT

The approach to water management worldwide is currently in transition, with a shift evident from purely centralised infrastructure to greater consideration of decentralised technologies, such as rainwater harvesting (RWH). Initiated by recognition of drivers including increasing water demand and increasing risk of flooding, the value of RWH is beginning to filter across the academic-policy boundary. However, in the UK, implementation of RWH systems is not straight forward; social and technical barriers, concerns and knowledge gaps exist, which currently restrict its widespread utilisation. Previously, these issues have been examined independently. The research described in this thesis highlights the need for interdisciplinary working to lower the barriers and resolve the concerns. Consequently, a combination of social and engineering research perspectives, methods and analysis is utilised to achieve the aim of the research: the production of a strategic framework to support the implementation of RWH in the UK. The framework is the culmination of empirically derived social and technical evidence bases including: surveys with householders and architects; interviews with small to medium enterprises (SMEs); a design and performance evaluation of a non-domestic RWH system; non-domestic water closet (WC) monitoring to develop a demand profile and a water quality study and health impact assessment (HIA) of a non-domestic RWH system. Results indicate that householders were willing but not able to implement RWH, due to financial constraints and perceived maintenance burdens. For SMEs 5 ‘implementation deficit categories’ were identified, which undermined their ability to implement. The use of continuous simulation tools, with appropriate data, need to be promoted and the non-domestic demand profile derived was distinctly different to the well-established domestic profile, yielding implications for system design. The non-domestic RWH system was able to achieve an average water saving efficiency of 97% for the period monitored and the HIA quantified the risk to health as being within the recognised screening level. Triangulation of the results into an integrated socio-technical evidence base facilitated the identification of three core strategy aims, their corresponding actions and actors (stakeholder groups). The overall strategic framework is presented in the form of a Venn diagram. It is unlikely the comprehensive nature of the strategic framework would have been achieved, if the interdisciplinary process had not been undertaken. Therefore adoption of a socio-technical approach to implementation is vital, if RWH in the UK is to transition from novel to mainstream.

To Graham and Pete – I guess you were right

When you see clouds gathering, prepare to catch rainwater.
African proverb, Gola Tribe.

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LIST OF ABBREVIATIONS AND NOTATIONS

3D	Three dimension	
A	Catchment area	m^2
AAP	Area Action Plan	
AAPOR	American Association for Public Opinion Research	
ACT	Australian Capital Territory	
ANOVA	Analysis of variance	
APART	Advanced Psychometric and Reaction Test	
APHA	American Public Health Association	
ARC	Aqualogic Rainwater Collection	
ARID	Australian Rainwater Industry Development Group	
ASCII	American Standard Code for Information Interchange	
BASIX	Building Sustainability Index	
BAU	Business as usual	
BBC	British Broadcasting Cooperation	
BC	Before Christ	
BC	Broadclose	
BMP	Best management practice	
BMRB	British Market Research Bureau	
BMS	Building Management System	
BOD	Biological (or Biochemical) oxygen demand	mg/l
BOD_5	5-day biological (or biochemical) oxygen demand	mg/l
BPS	British Psychological Society	
BREEAM	Building Research Establishment Environmental Assessment Method	
BSI	British Standards Institute	
BS	British Standard	
BWD	Bathing water directive	
BWL	Bottom water level	mm
CAMS	Catchment Abstraction Management Plans	
CAT	Centre for Alternative Technology	
CCW	Consumer Council for Water	
CDIAC	Carbon Dioxide Information Analysis Centre	
C_f	Run-off coefficient	
CFMP	Catchment Flood Management Plan	
CfSH	Code for Sustainable Homes	
cfu	Colony forming units	
CIPHE	Chartered Institute for Plumbing and Heating Engineering	
CIRIA	Construction Industry Research and Information Association	
CIWEM	Chartered Institution of Water and Environmental Managers	
CO_2	Carbon dioxide	
COD	Chemical oxygen demand	mg/l
CRC	Cooperative Research Centre	
CSO	Combined sewer overflow	
CWS	Centre for Water Systems	
D	Demand	m^3
DALY	Disability Life Affected Years	
DBIS	Department for Business, Innovation and Skills	
DCC	Devon County Council	
DCLG	Department for Communities and Local Government	

D_d	Average daily demand	m^3
DECC	Department for Energy and Climate Change	
DEFRA	Department for Environment, Food and Rural Affairs	
DER	Department of Environmental Resources	
DETA	Decentralised Environmental Technology Adoption	
DEWHA	Department of the Environment, Water, Heritage and the Arts	
DFA	Discriminant Function Analysis	
DGNB	Deutsche Gesellshaft fur Nachhaltiges Bauen	
DI	Diffusion of Innovation	
DIN	Deutsches Institut fur Normung	
DLL	Dynamic Link Library	
DMA	District metered area	
DRIP	Disaggregated Rectangular Intensity Pulse	
DTI	Department of Trade and Industry	
DURIPA	Designated Urban River Inundation Prevention Act	
E	Depression storage loss	
E(kWh)	Energy	kWh
E_2	Improved energy consumption	kWh
EA	Environment Agency (England and Wales)	
EAs	Early Adopter	
E_C	CO_2 emitted from electricity	Kg/kWh
EC	European Community	
ECA	Enhanced capital allowance	
ECO_2	Carbon dioxide from pump energy consumption	kg
EGRIF	Engineering Guideline for Rainwater Infiltration Facilities	
EM	Ecological Modernisation	
EMy	Early Majority	
ENT	Enterococci	
EPA	Environmental Protection Agency (Australia)	
E_{POT}	Energy consumed during pump operation	kWh
E_{PS}	Energy consumed on pump start up	kWh
E_{PST}	Total energy consumed on pump start	kWh
EST	Energy Saving Trust	
E_T	Water saving efficiency	%
E_{TOT}	Total pump energy consumption	kWh
EU	European Union	
F	Filter coefficient	
F&WMA	Flood and Water Management Act	
FAQ	Frequently Asked Question	
FC	Faecal coliform	no/100ml
FIO	Faecal indicator organism	
FPEB	Framework for Pro-Environmental Behaviour	
FRMP	Flood Risk Management Plan	
FS	Faecal streptococci	
GAP	Global Action Plan	
GDP	Gross domestic product	
GIS	Geographical Information Systems	
GRP	Glass reinforced plastic	
GSBC	German Sustainable Building Certificate	
GWR	Greywater reuse	
H_C	Header capacity	m^3
HDPE	High density polyurethane	

HIA	Health impact assessment	
HMRC	Her Majesty's Revenue and Customs	
HPC	Heterotrophic plate count	
HSD	Honestly significant difference	
HZ	Home zone	
I	Innovator	
ICP1	Innovation Centre Phase 1	
ICP2	Innovation Centre Phase 2	
ICP-MS	Inductively coupled plasma mass spectrometry	
IDC	Implementation deficit category	
IDF	Intensity-Duration-Frequency	
IETC	International Environmental Technology Centre	
IT	Information Technology	
IWM	Integrated water management	
L	Laggard	
LA	Local authority	
LDF	Local Development Framework	
LH	Littleham	
LID	Low impact development	
LIUDD	Low impact urban design and development	
LM	Late Majority	
MANOVA	Multi-variate analysis of variance	
MCSDS	Marlowe-Crowne Social Desirability Scale	
MDG	Millennium development goal	
MDPE	Medium density polyurethane	
MPMSAA	Master Plumbers' and Mechanical Services Association of Australia	
MTP	Market Transformation Programme	
MUSIC	Model for Urban Stormwater Improvement Conceptualisation	
NA	Not applicable	
NEC	National Exhibition Centre	
NGO	Non-governmental organisation	
NIC	National Charrette Institute	
NOTA	None of the above	
NPV	Net present value	
NRTDIH	National Rainwater Tank Design and Installation Handbook	
NSW	New South Wales	
NTU	Nephelometric turbidity units	
NWC	National Water Commission	
NWI	National Water Initiative	
O_D	Operating duration	h
O_{DO}	Pump operating duration	h
O_{DS}	Pump start-up operating duration	h
OFWAT	Water Services Regulation Authority	
OGC	Open Geospatial Consortium	
OSD	On site detention	
O_V	Volume consumed pumped during pump operation	m^3
P	User-defined percentage	
PAH	Polycyclic aromatic hydrocarbon	
PAR	Participatory action research	
P_C	Pump capacity	m^3/h
PCA	Principal Component Analysis	

PCC	Per capita consumption	
P_E	Pump efficiency	%
PET	Polyurethane	
PFWL	Partial flush water level	
P_I	Pump input power	kWh
PIR	Passive infra-red	
PPS	Planning Policy Statement	
P_R	Pump rating	kW
P_S	Number of pump start-ups	
PURRS	Probabilistic Urban Rainwater and wastewater Reuse Simulator	
PVC	Polyvinyl chloride	
Q	Inflow or rainfall-runoff	m^3
QDA	Qualitative data analysis	
QMRA	Quantitative Microbial Risk Assessment	
R	Rainfall	m^3
R^2	Coefficient of determination	
RAE	Royal Academy of Engineering	
RBMP	River Basin Management Plan	
RHCC	Rain Harvesting Capacity Centre	
RIBA	Royal Institute of British Architects	
RSD	Rain-Storage-Drain	
RSS	Regional Spatial Strategy	
RW	Rainwater	
RWH	Rainwater harvesting	
S	Storage capacity	m^3
SA	Southern Australia	
SEQ	South East Queensland	
SF	System function	
S_F	Start-up factor	
SME	Small to medium enterprise	
SMIS	Stormwater management information system	
SPSS	Statistical Package for the Social Sciences	
SUDS	Sustainable drainage systems	
S_V	Percentage of volume consumed pumped during pump start-up	%
SW	Storm water	
SWCCIP	South West Climate Change Impacts Partnership	
SWM	Sustainable water management	
SWMP	Surface water management plan (not to be confused with a Site waste management plan, which is not used within this thesis)	
SWMT	SUDS water management train	
SWRDA	South West Regional Development Agency	
t	time interval under consideration	
T_1	Float switch on level	%
T_2	Float switch off level	%
TC	Total coliform	no/100ml
TDS	Total dissolved solids	mg/l
TSS	Total suspended solids	mg/l
TT	Technology Transition	

TTC	Thermotolerant coliform	
TVC	Total viable count	no/ml
TWDB	Texas Water Development Board	
UK	United Kingdom	
UKRHA	UK Rainwater Harvesting Association	
UKWIR	UK Water Industry Research	
UNCED	United Nations Conference on Environment and Development	
UNDC	United Nations Development Corporation	
UNEP	United Nations Environment Programme	
USA	United States of America	
USB	Universal Serial Bus	
UV	Ultra violet	
UWOT	Urban Water Optioneering Tool	
UWWTD	Urban Waste Water Treatment Directive	
V	Volume of rainwater in store	m^3
V_1	Volume pumped during operation	m^3
V_2	Volume pumped during start-up	m^3
VBA	Visual Basic for Applications	
WC	Water closet	
WDM	Water demand management	
WDS	Water distribution system	
WFD	Water framework directive	
WHO	World Health Organisation	
WQ	Water quality	
WRAS	Water Regulations Advisory Scheme	
WRZ	Water resource zone	
WSD	Water saving device	
WSPs	Water service providers	
WSUD	Water sensitive urban design	
WWTP	Wastewater treatment plant	
X	Number of days of storage	
Y	Yield from store	m^3
YAS	Yield after spillage	
YBS	Yield before spillage	
YLD	Years Lived with a Disability	
YLL	Years of Life Lost	

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1 CHAPTER 1: INTRODUCTION

1.1 Background

Rainwater harvesting is experiencing a renaissance. From Antwerp (Belgium; Konig, 2001) to Zamora (Mexico; CONAGUA, 2009) systems are being fitted to provide a source of non-potable or potable water. Climate change and population growth, as well as other pressures, are increasingly having an impact on water resources across the globe (Ashley *et al.,* 2003). Incidences of flooding increase year on year, as development takes its toll on natural drainage systems or invades areas naturally at risk from flooding. Whatever the driver or end use, the reason is the same – recognition that water is our most precious resource and needs protecting (Murase, 2009).

This recognition has been nearly two decades in the making; taking action on humanity's environmental impact first appeared on the worldwide agenda in 1992 (Konig, 2001). Since then, sustainable development has permeated politics and many countries now follow strategies to develop more 'sustainably' (DEFRA, 2005). The water sector has ridden along with the changes, with 'sustainable water management' (SWM) now at the top of many country's agendas.

Adoption of the SWM approach results from decades of research into different sources of water as alternatives to the centralised water distribution system (WDS) (such as greywater, RWH, desalination), demand management (water saving devices, behaviour change) and appreciating the value of storm waters and wastewaters as *sources* of water, not nuisances to be hidden away (De Graaf, 2009). The UK is beginning to realise the value of the SWM approach, taking heed of the experiences of other countries where drought has turned the traditional view of the centralised WDS on its head (Coombes *et al.,* 1999) or where monsoon extremes make traditional approaches to sewer design redundant (Sugai, 2009; Mun *et al.*, 2009).

RWH is not a universal remedy and is certainly not a 'one size fits all' technology, but it forms a valuable part of the SWM approach; having dual benefits of water supply and stormwater source control. Many countries, including the UK, are recognising these benefits and returning to one of the oldest forms of water management on the planet (Crasta *et al*, 1982).

1.2 Research Perspective

Over the last five years the status of RWH in the UK has transitioned from that of a novelty, only present in SWM demonstration projects, to that of a practical solution to help supplement mains water use. However, the transition has not yet reached the level of RWH becoming a mainstream or accepted component to successful SWM planning. Despite a number of sustainability and policy drivers, technical and institutional barriers to the implementation of RWH still remain (these are discussed in detail in Chapter 2). This thesis aims to produce a strategic framework to help to overcome these barriers, by identifying and quantifying the barriers as implementation deficits and suggesting a comprehensive strategy to reduce them.

The majority of previous studies on RWH in the UK (some of these are described in Chapter 2) have taken either a social or technical viewpoint. This study intends to contrast these studies by presenting a socio-technical viewpoint. This view is taken, as in order to identify barriers, there are many perspectives to represent. In order to appropriately implement RWH into a development of any scale, the available resources as well as site specific constraints need to be understood. Furthermore, user behaviour plays a major role in the performance of RWH systems. Uninformed user behaviour can compromise the benefits achieved by RWH systems. Therefore it is important for these perspectives to be represented otherwise the resulting research would only, to use an urban development-based metaphor, represent one side of the fence and not the whole housing estate.

In order to represent both sides of the socio-technical fence, it was decided to undertake an interdisciplinary approach to the research. In performing interdisciplinary research, both the perspectives and methodologies of the disciplines included should be identified and adopted. In being termed ‘sustainable’ RWH is, by definition, an interdisciplinary technology, as it aims to provide benefits across the three pillars of sustainability (reduced water costs (economy), reduced impact on water resources (environment) and security of access to water (society)). Within this research the following disciplinary perspectives have been adopted, which have informed the development and implementation of the research design.

The main disciplinary perspectives that have informed the research design are geography, sociology and engineering, which are summarised in Figure 1.1 and contextualised in terms of the present research as follows:

- Geography – interaction of human and physical environments. In terms of its relevance to the SWM context, the human environment utilises water resources from the physical environment. It could be argued that Society's current ambition is to lessen the impact of consumption of water resources by adjustments to the human, rather than natural, environment (via the use of demand management and alternatives such as RWH).

- Sociology – understanding people's motivations and behaviours. In the context of SWM this is taken as understanding what is needed to enable people to consider alternatives and identifying means of support for the implementation of appropriate techniques/measures.

- Engineering – developing new technologies to meet society's needs. Contextually, for RWH this takes the form of undertaking investigations into RWH system design and performance to understand limitations in their application and facilitate improvements.

A further over-arching perspective informing the research design is that of sustainability, which advocates adherence to the three pillars of balancing the needs of the environment, the economy and the society. In the context of this thesis it is not considered to be a discipline in its own right, as it requires the interaction and utilisation of tools and methods of a number of disciplines to follow an ever-changing journey to achieve its (movable) objectives.

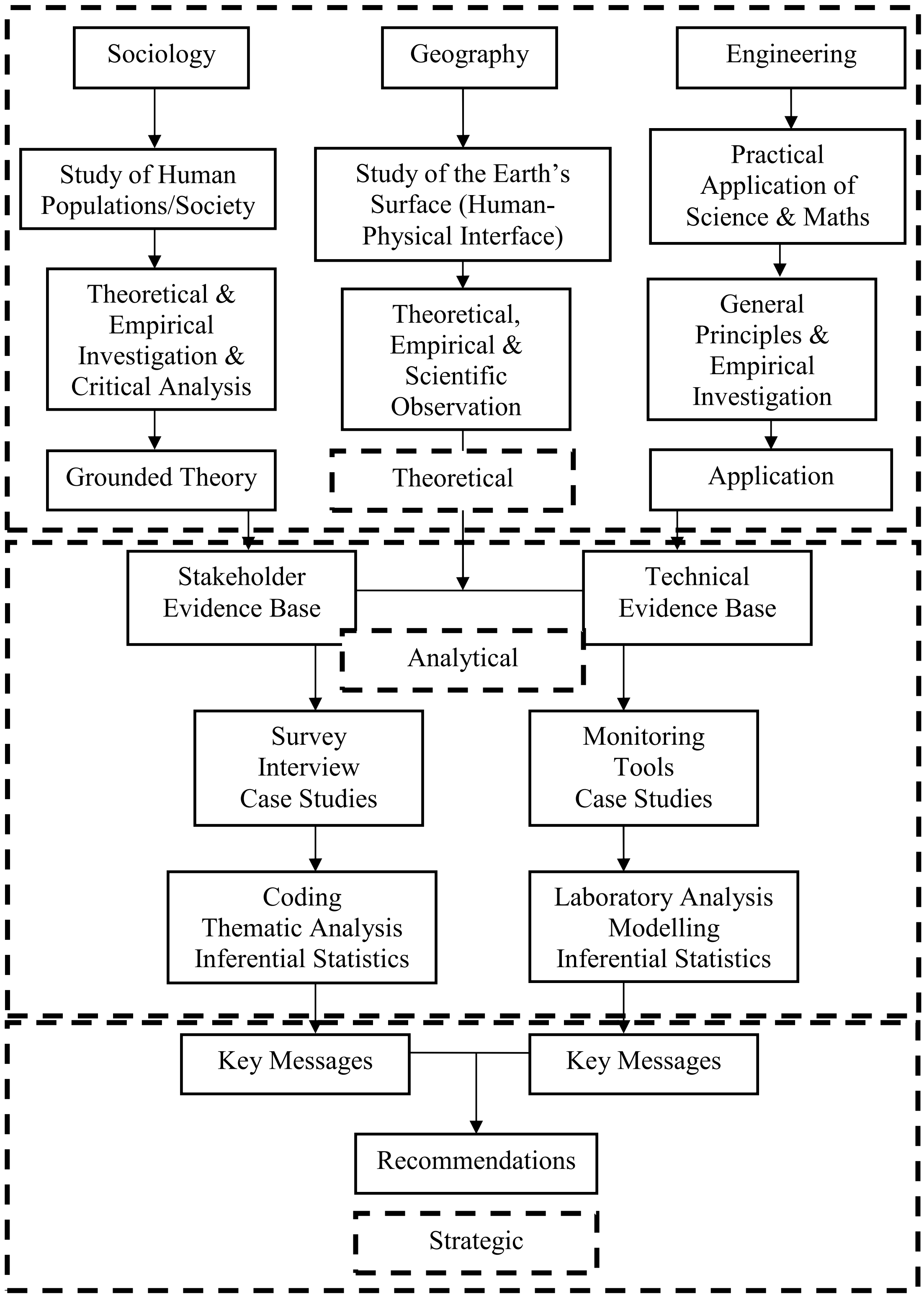


Figure 1.1 Disciplinary perspectives informing the philosophical viewpoint and design of the research and their level of operation

Figure 1.1 also highlights the levels of operation of the disciplinary viewpoints, which contribute to the research design followed within this thesis. The research design consists of theoretical, analytical and strategic components. As can be seen the principles and methodologies of each discipline are truly integrated in the production of the last component; the strategic framework to support the implementation of RWH in the UK, which represents the primary aim of this thesis. The aim and objectives are described further in the following section. The research design also provides a transferable approach to evaluating the generic implementation process (success or failure), which could be applied to the implementation of other SWM techniques (such as greywater reuse).

In integrating these disciplinary perspectives, the research also hopes to contribute to the current paradigm shift occurring within the engineering discipline, which is a transition to a more stakeholder based perspective. A recent emergence in the Engineering discipline, which both Geography and Sociology (and indeed Science) have a long history of debating, is consideration of the 'Philosophy of Engineering'. This provides reflection of what engineering is, what engineers do and how their work impacts society (McCarthy, 2006). It is in contrast to the historic Royal Charter of the Institution of Civil Engineers perspective, which described the role of the engineer as:

"….harnessing the great forces in nature for the use and convenience of Man."

(RAE, 2004), which has been recognised as being outdated and has recently been reviewed. Under the revised viewpoint, engineering must be considered a socio-technical discipline for which traditional mathematical or physical modelling may not provide all the knowledge required to assess a system in terms of its impact on people (RAE, 2004).

With respect to this, in this thesis the 'socio' perspective is provided by enriching knowledge of sociological viewpoints and the 'technical' perspective provided by enriching knowledge of technical issues, both in relation to RWH in the UK. In bringing together disciplines that are traditionally viewed as being diametrically opposed (i.e. Engineering and Sociology) and have limited understanding of the other, it can be argued that Geography provides an appropriate 'mediating' role, as the discipline has a long-standing tradition of comparing and contrasting approaches to knowledge gathered about both the human and physical environments.

Consequently, the research project as a whole provides case studies representing a socio-technical meta-analysis (or 'triangulation' (Hayes, 2000)), but not in the classical sense that it pools statistical results. It does this in the sense that it combines data from several studies to form a single analysis; that of the current status of RWH in the UK. By providing this viewpoint, recommendations can subsequently be made to reduce deficits, enhance implementation and thereby provide a strategy to facilitate the transition of RWH from novelty to mainstream.

1.3 Aim, Objectives and Research Questions

As established in the preceding introductory sections, RWH has yet to reach mainstream status as a SWM technique. In order to facilitate a transition to this status, the aim of this thesis is:

"To develop a strategic framework to support the implementation of RWH in the UK."

In order to achieve this aim the following objectives have been determined:

- **Objective 1:** Identify drivers for promoting RWH;

- **Objective 2:** Establish known and unknown barriers and knowledge gaps;

- **Objective 3:** Enrich the socio-technical evidence base relating to RWH;

- **Objective 4:** Develop policy and practice recommendations to enhance the success of future RWH projects.

These objectives are summarised in Figure 1.2, which also outlines the general range of research methods utilised; these and justification of their selection are described in more detail in the next section and proceeding chapters. The above objectives are quite broad and therefore a number of research questions were determined that better facilitated the selection and application of the research methods. The research questions for each objective are:

- **Objective 1:** Identify drivers for promoting RWH;

i. What are the reasons for promoting RWH in the UK?
ii. How is RWH being promoted in the UK?

- **Objective 2:** Establish known and unknown barriers and knowledge gaps;

iii. What are the known barriers to RWH implementation in the UK?
iv. What *potential* barriers are there to RWH implementation in the UK?

- **Objective 3:** Enrich the socio-technical evidence base relating to RWH in the UK;

v. Is the UK public aware of and willing to implement RWH?
vi. Are building design professionals aware of RWH and the appropriate design documentation associated with it?
vii. How have SMEs found the RWH implementation process?
viii. What is the health risk associated with flushing toilets with RWH?
ix. What impact do physicochemical parameters have on RWH system function?
x. How do RWH system design methods perform in comparison with empirical data?
xi. How does an office-based RWH system perform in terms of water saving efficiency?
xii. What energy consumption and carbon emission implications are there in using RWH?
xiii. Are non-domestic demand-side parameters adequately represented within system designs?

- **Objective 4:** Develop policy and practice recommendations to enhance the success of future RWH projects.

xiv. What modifications are required within current RWH system promotion and implementation processes to facilitate greater uptake?

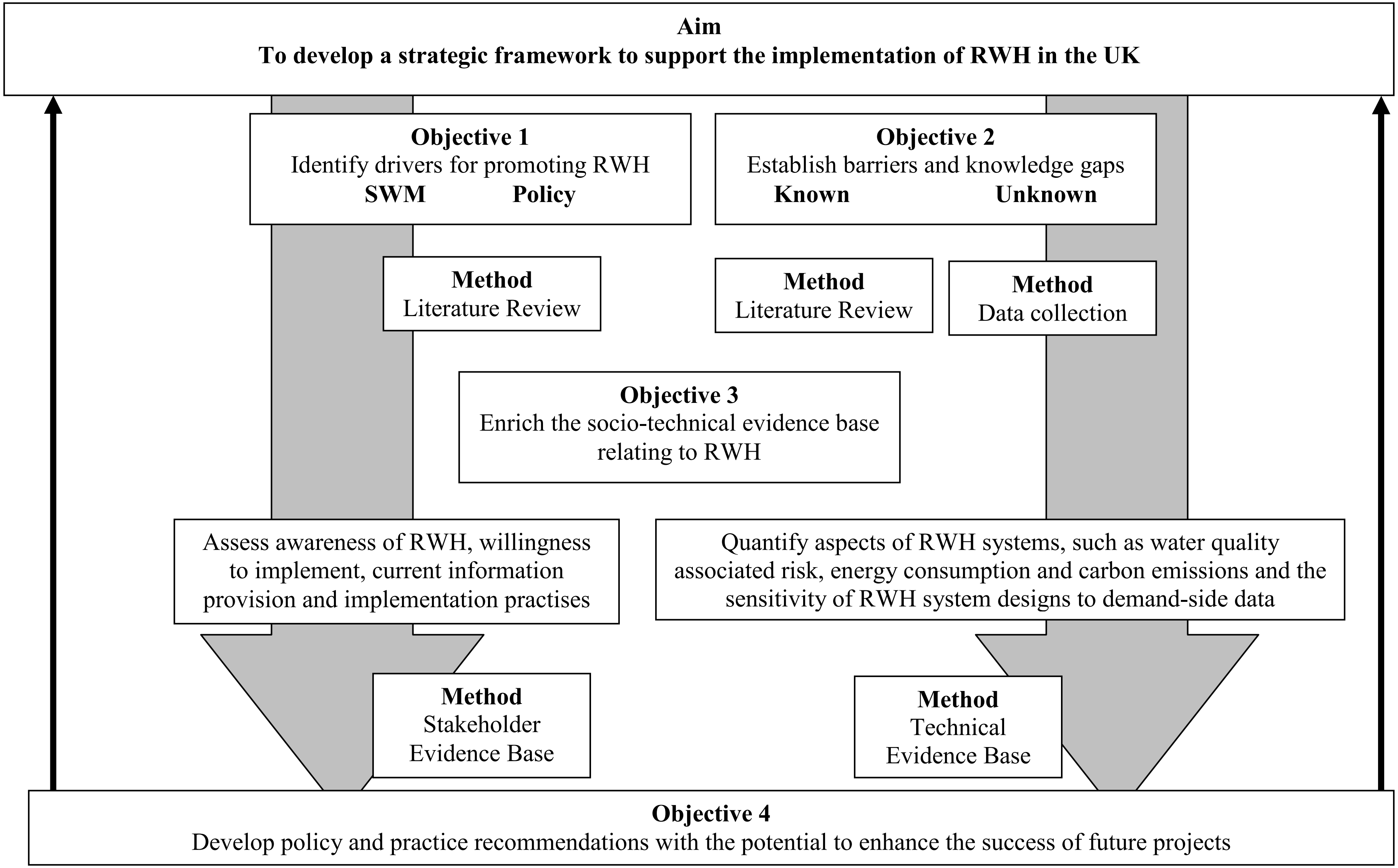


Figure 1.2 Overview of the aim, objective and general methods used in the research design

1.4 Research Approach

In undertaking an interdisciplinary project, it was natural to under-pin the research approach and consequently the selection of the methods with a combination of grounded theory (from sociology) and the scientific method (from engineering/geography). These approaches contrast in that grounded theory advocates the construction of a theory through the exploration of data (Robson, 2002), whereas the scientific method advocates the construction of a theory which is then rejected or accepted through the collection of data (Robson, 2002). In this thesis a grounded theory approach is applied to construct an understanding of the experiences and needs of a range of stakeholders. The scientific method is used to test hypotheses regarding RWH system performance and harvested rainwater quality.

Forming a research design from the combination of these approaches led to the selection of methods that would complement socio-technical view points and therefore provide a comprehensive evidence base on which to develop recommendations and a strategic framework. A further consideration in selecting the most appropriate methods was the characteristics of the phenomena under investigation. This resulted in the use of a case study approach, which is utilised by a range of disciplines to explain complex phenomena (Yin, 2003). The interdisciplinary socio-technical perspective adopted in the research design resulted in exposure to a wide range of methods through which data could be collected. This was beneficial due to the diverse range of objectives and research questions devised to achieve the project aim. Consequently, both quantitative and qualitative research methods were utilised within the development of social and technical evidence bases.

Deductive thinking undertaken in relation to the literature review (Chapter 2) facilitated the selection of the areas on which to focus data collection (please refer to Chapter 2 for full discussion of this process). The full range of methods utilised within the multiple-case study structure and the chapters in which they are fully described is as follows:

Stakeholder Evidence Base:

- A survey with householders, office tenants and architects, Chapter 3;

- Interviews with SMEs, Chapter 4.

Technical Evidence Base:

- Water quality monitoring of an office building RWH system, Chapter 5;

- Evaluation of design tools and their application, Chapter 6;

- Evaluation of performance of an office building RWH system, Chapter 6;

- Development of a non-domestic WC demand profile, Chapter 6.

Each of these methods required a different type of analysis, which included thematic/template analysis of interview transcripts and numerical/statistical analysis of survey data and parameter values (for example, water quality parameters). The type of analysis undertaken is described in the relevant chapter.

Additionally, the utilisation of a range of interdisciplinary techniques required the author to assume different roles, depending on the requirements of the stakeholders and types of data to be collected. For example, the office-building performance evaluation required the author to become both analyst and facilitator, to ensure that system faults were rectified to enable data collection. This meant the author inadvertently became involved in participatory action research (PAR), a research method in its own right, where the researcher makes an intervention in order to examine the effect of the intervention (Robson, 2002). However, it should be noted the interventions were made specifically to facilitate data collection, rather than to examine their impact; being able to observe their impact was merely an incidental result of intervening. The roles of the author in relation to the different methods employed are summarised in Table 1.1.

Table 1.1 Roles assumed by the author in relation to research methods utilised

Method	Role
Literature Review	External observer and research designer
Interview	Interviewer, external observer, analyst and advisor
Survey	External observer and analyst
Water quality monitoring	External observer and analyst
Design tool application evaluation	Analyst and reflective practitioner
Performance evaluation	External observer, analyst, reflective practitioner and facilitator/advisor
Meta-analysis/triangulation	Reflective practitioner

1.5 Originality and Contribution

The work presented in this thesis can be regarded as original at the following levels:

- Theoretical;
- Methodological;
- Practical.

It is original in the following ways:

- Embeds an innovative, interdisciplinary research design combining sociological and engineering perspectives, their associated approaches and research methods;
- Expands on previous studies to include the viewpoints of stakeholders not previously considered in research on RWH (SMEs and architects);

- Identifies and quantifies previously unknown barriers (‘implementation deficits’), such as low confidence in expertise and process support and a low willingness and ability to undertake or fund crucial maintenance activities;

- Recommends an integrated socio-technical strategic framework of actions to enhance the success of future RWH projects.

The ways in which the work was undertaken can also be regarded as its contribution. Furthermore, the work makes the following additional contributions to knowledge:

- Provides a comprehensive case study of a RWH system in an office building, at implementational and operational levels;

- Develops an improved method for benchmarking the operational energy consumption and carbon dioxide emissions of RWH systems;

- Quantifies WC flushing in a non-domestic building, develops a demand profile and contrasts its characteristics to the well-established domestic demand profile, as well as designing and manufacturing a flush counting device;

- Contributes to increasing the recognition of SWM measures/RWH as socio-technical systems, rather than just technical systems;

- Establishes that a transition to better RWH system design and implementation processes needs to be facilitated at an institutional level, through the strengthening and development of policy recommendations and product innovation.

1.6 Thesis Structure

For clarity, the structure of the thesis is outlined in Figure 1.3. This flow chart summarises which chapters relate to the overall aim, the different objectives and aspects of the research design.

Chapter 2 sets the context for the research, by providing an overview of the current drivers for promoting RWH in the UK, as well as the barriers to implementation. Additionally, it provides a background to the technical aspects of RWH systems, in terms of their components and approaches used to design them. Furthermore, it reviews previous social research into SWM and RWH to identify previous approaches and potentially unexplored socio-technical viewpoints in order to establish a conceptual framework to provide a backdrop against which the rest of the thesis is set.

Chapter 3 presents the results of a survey conducted with householders to establish their receptivity to RWH, as well as their experiences. Chapter 4 follows, which describes interviews conducted with SMEs regarding their experiences with the RWH system implementation process. Chapter 5 examines the health risk posed by flushing WCs in an office building with RWH, by undertaking a water quality monitoring study and health impact assessment. Chapter 6 provides insights into RWH design tool application and system performance, as well as an investigation of non-domestic building demand. It also outlines a method for estimating system operational energy requirements.

Chapter 7 reflects on the literature review and the results of chapters 2 to 6. It integrates the insights and key messages into a strategic framework of recommendations for action to support the implementation of RWH in the UK. The thesis concludes with Chapter 8, which provides a summary of the main conclusions, an impact plan for disseminating the research findings and ideas for further work.

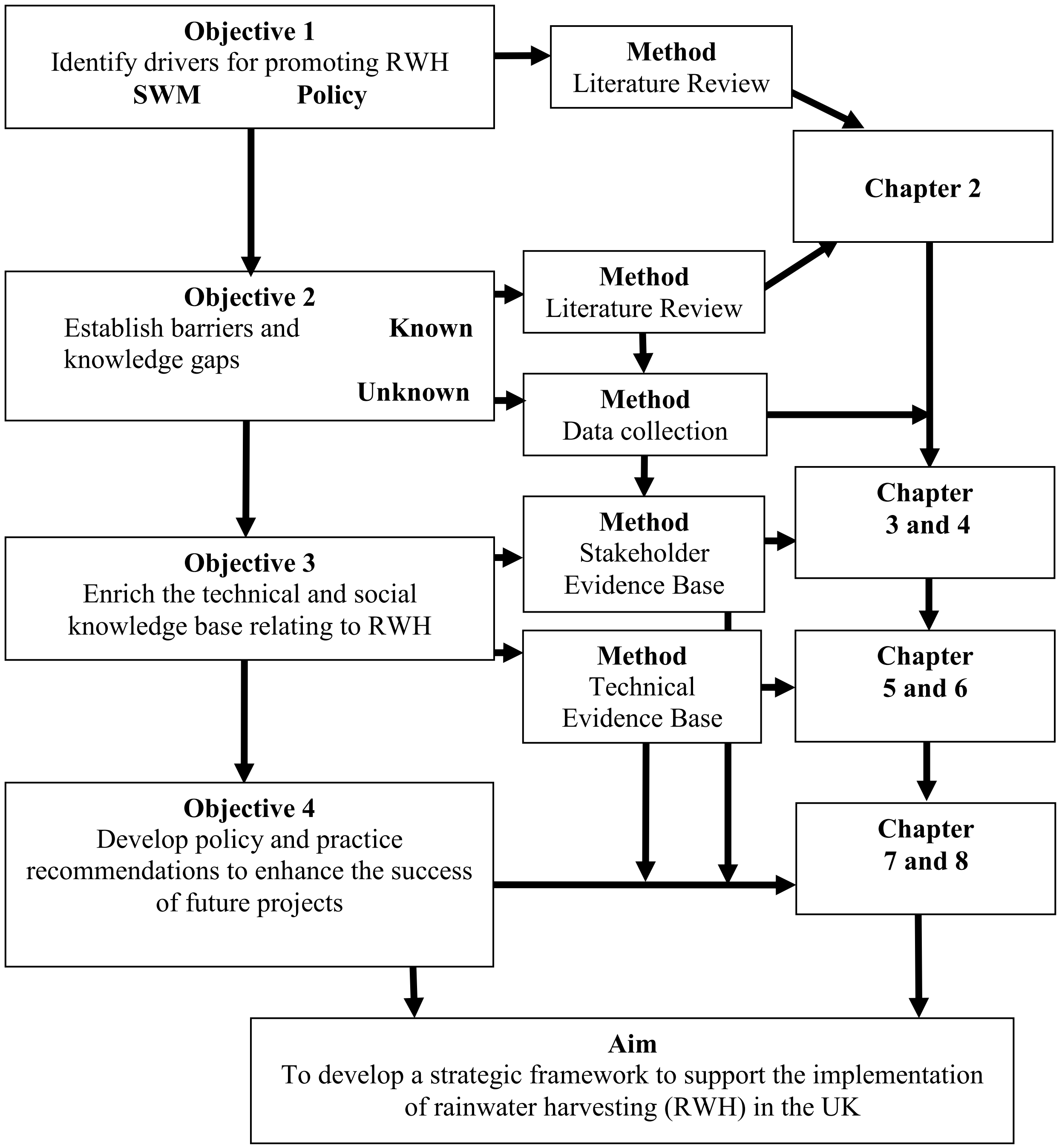


Figure 1.3 Flow chart summarising connections between the aim, objectives, methods and chapters of this thesis

2 CHAPTER 2: LITERATURE REVIEW

The previous chapter has outlined the research perspective and approaches taken in this thesis. This chapter provides a detailed review of the literature considered throughout the course of the project. The sub-topic areas were identified by taking a holistic view of RWH and the context in which it sits – that being within the water management sector. Due to the socio-technical nature of the thesis, it is necessary to provide a background to a range of topics including water policy and SWM. Sub-topics are listed below and subsequently this list provides an overview of the main section headings of this chapter:

- **Sustainable Development, SWM and IWM** – locating SWM/IWM in the context of sustainable development;
- **SWM in the UK** – setting the national context within which the research sits;
- **RWH as a SWM Technique** – narrowing consideration of SWM to RWH, including a technology review and discussion of the position of RWH in the UK in comparison with other countries;
- **SWM, RWH and Social Research** – exploring a range of social research studies and their potential relevance to supporting RWH in the UK;
- **Chapter Summary and Implications** – drawing together the main points of discussion, upon which the subsequent research project is built.

By reviewing these areas of the literature it is hoped to fulfill the first two objectives and their associated research questions, which are:

- **Objective 1:** Identify drivers for promoting RWH;
    - What are the reasons for promoting RWH in the UK?
    - How is RWH being promoted in the UK?
- **Objective 2:** Establish known and unknown barriers and knowledge gaps;
    - What are the known barriers to RWH implementation in the UK?
    - What *potential* barriers are there to RWH implementation in the UK?

2.1 Sustainable Development, SWM and IWM

Identifying a widely agreed definition of SWM or IWM (also sometimes referred to as 'total water management') would probably require the undertaking of a research project in itself (Biswas, 2004). However, for the purposes of this thesis, they are defined as meaning:

SWM - '*…to manage our water resources while taking into account the needs of present and future users.*'

And,

IWM – '*a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*' (Biswas, 2004).

IWM can also mean facilitating an interaction between water supply, wastewater and storm water at a regional, catchment, local and development scale, where it becomes known as SWM. This encompasses 'sustainable drainage systems' (SUDS)) in the UK (CIRIA, 2005), 'Best Management Practices' (BMPs) or 'Low Impact Development' (LID) in the USA (DER, 1999), 'Low Impact Urban Design and Development' (LIUDD) in New Zealand (Van Roon *et al.,* 2006) or 'Water Sensitive Urban Design' (WSUD) in Australia (Coombes *et al.*, 1999), (Figure 2.1).

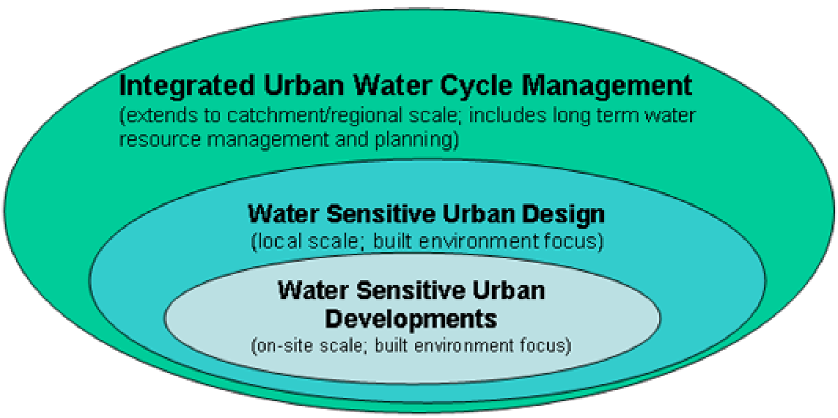


Figure 2.1 Conceptual model of urban integrated water cycle management and related concepts in Australia (NWC, 2009)

Both SWM and IWM approaches realise that it is beneficial for water to remain in urban catchments (Hurley *et al.,* 2008). As the terms are used interchangeably, the term SWM will subsequently be used to represent both SWM and IWM within this thesis. SWM has its origins in the pursuit of sustainable development, first highlighted in the 1972 Club of Rome project, The Limits to Growth. This highlighted the impact of the human footprint on the physical limits of the planet. The basic principle illustrated the Earth's resources are not infinite and depletion of natural resources and excess industrial and agricultural emissions would force an end to global human growth (Meadows *et al.,* 1972). Sustainability subsequently appeared on the global agenda in 1992 when the UN Conference on Environment and Development (UNCED) in Rio de Janeiro proposed the 'Rio Declaration on Environment and Development'. This laid the foundations for responsible action towards planet Earth. The declaration also stated that safe access to potable water was a basic human right (Konig, 2001).

UNCED also called on governments to produce sustainable development strategies, sustainable development being defined as: *"…development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*, as well as adhering to the three pillars of sustainability (economy, society, environment) or the triple bottom line (Glavic and Lukman, 2007; Ashley *et al.,* 2008). This took on the guise of the 'Local Agenda 21 – A Framework for Local Sustainability' programme (Leggett *et al.*, 2001). This empowered local authorities to develop strategies based on the needs and requirements of their communities; such programmes worked at both the county and city scale.

The 1997 World Water Forum in Morocco identified it was as important to engage the public as it was politicians in water awareness. Rainwater management was added to the agenda at the 2000 Forum in The Hague, where various seminars on global case studies, including some from Germany and Japan, were presented (Konig, 2001). Recommendations included: the further development of technologies; stimulating interest with the general public; Governments to produce a policy framework addressing social, economic and environmental benefits; development of a framework for sharing best practices; encourage community participation and government involvement and to recognise the role of individuals in environmental management. This included promoting RWH as part of the solution to poverty and the degradation of the environment. Furthermore, the International Environmental Technology Centre (IETC) of the UN's Environment Programme (UNEP) featured SUDS and RWH in the International Symposium on Efficient Water Use in Urban Areas in 1999. It focused on securing water by efficient use of existing sources to avoid supply issues (Konig, 2001).

Central to the concept of sustainable development is the linking of ecologically sound practises with economic viability under the concept of 'think globally – act locally' (Coombes *et al.*, 1999). This enables the achievement of environmental goals via positive, affordable action in communities. Currently there is a vast range of global activities being undertaken in relation to recognition of the need for sustainable development. Throughout the world, water resource issues are receiving heightened attention, under the scope of various campaigns such as 'Making Poverty History' and the United Nation's Millennium Development Goals (MDGs), (Ashley *et al.,* 2008). In Europe, the European Union (EU) Water Framework Directive (WFD (2000/60/EC)) has far-reaching consequences for water resources management. The requirement to have 'good status' water bodies by 2015 will bring with it numerous challenges to both water protectors and water suppliers (Giupponi, 2007). Additionally, the EU Floods Directive (2007/60/EC) will impact the way in which flood risk management activities are undertaken (DEFRA, 2009a).

The UK Government is currently driving forward a sustainable development strategy (DEFRA, 2005), which aims to address:

- The consequences of climate change;
- The increasing stress on resources and environmental systems;
- The increasing loss of biodiversity.

The strategy, 'Securing the Future', sets out a strategic framework to provide a consistent sustainability approach across the UK, covering the period up to 2020. The priority areas for immediate action are:

- Sustainable consumption and production;
- Climate change and energy;
- Natural resource protection and environmental enhancement;
- Sustainable communities.

The report acknowledges that the most significant pressures on the global environment arise from household energy and water consumption, food consumption, travel and tourism. It could be argued that water, its use and management, falls into all of these areas. Direct national indicators set out in the document in relation to water are:

- Water resource use: total abstractions from non-tidal surface and ground water sources and gross domestic product (GDP);
- Domestic water consumption: domestic water consumption per head;
- Water stress (to be developed to monitor the impacts of water shortages);
- Flooding (to be developed to monitor sustainable approaches to ongoing flood management);

The planning system was highlighted within the sustainability strategy as providing a framework to allow the ‘designing in from the outset’ of procedures to address water resource management (as well as other areas). Therefore the strategy provides a backdrop against which water-related policy is developed in the UK. Subsequently, SWM policies and approaches currently pursued in the UK are very focused on these indicators.

2.2 SWM in the UK

Building on the 2002 document ‘Directing the Flow – priorities for future water policy’ (DEFRA, 2002), in conjunction with the previously outlined sustainable development strategy, the UK government recognised it is facing and must respond to a number of water-related challenges including:

- Land-use and urban development – expected growth poses a challenge for water use;
- Water resources – under pressure from climate change and increased consumption;
- Climate change – likely to place more stress on water resources, including more frequent extreme weather events;
- Flood management – challenges presented by more frequent extreme weather events.

(DEFRA, 2002)

Other indicators for the health of water bodies are included, but are not discussed further here. Acknowledgment of these issues brought with it recognition of the need for new, more integrated and adaptable approaches to water management (DEFRA, 2002). This heralded the beginning of a policy level paradigm shift (or transition) away from a focus on traditional piped water and sewerage systems towards the use of SWM approaches in the UK, although actions in practice are still limited. These had been researched and advocated at an academic level since the 1980s (Brown *et al.,* 2006; Ashley *et al.,* 2008). This shift also highlighted the need for greater engagement with a wider range of stakeholders in order to drive WFD objectives forward (Ashley *et al.,* 2003; Ashley *et al.,* 2008).

Subsequently, in the last five to ten years a number of consultations, policies and strategies relating to SWM have emerged. Some of these are summarised in Table 2.1. The list is not intended to be fully comprehensive and inevitably some will be missing. Future Water is the most recent strategy to drive the SWM approach in the UK (DEFRA, 2008c). It is the UK government's 'water strategy for England' and provides a comprehensive review of the water sector in England, including how it relates to other sectors such as housing, industry and agriculture and the interconnectivity of these sectors with greenhouse gas emissions.

In follow-up to this and after several years of increased incidence of flooding, on the 9th April 2010 the government passed the Flood and Water Management Act (F&WMA; previously known as the Flood and Water Management Bill), (DEFRA, 2010). This has the potential to improve the pursuit of a SWM approach via means such as placing SUDS within the responsibility of Local Authorities (LAs) to assist in their adoption and maintenance. It is hoped this will facilitate their increased implementation. The need for SWM is now well established and current activity focuses on how to implement and achieve the transition to it (Reed, 2009). The following two sub-sections provide discussion on the two main drivers for SWM in the UK, outlined by the previously mentioned indicators, those being increased water demand and increased flood occurrence.

Table 2.1 Chronology of the main published documents related to SWM in the UK over the last ten years

Document	Department	Year
Directing the Flow	DEFRA	2002
Making Space for Water	DEFRA	2004
Securing the Future	DEFRA	2005
Building a Greener Future: Towards Zero Carbon Development	DCLG	2006a
Code for Sustainable Homes	DCLG	2006b
Water Efficiency in New Buildings	DCLG and DEFRA	2006
Planning Policy Statements (PPS): 25 (flood risk) and	DCLG	2006c
1 (climate change and sustainable development)	DCLG	2007
Sustainable Construction Strategy	DEFRA (*et al.*)	2007
Conserving Water in Buildings	EA	2007
Funding and Charging Arrangements for SUDS	DEFRA	2007a
Powers to Restrict Non-Essential Uses of Water	DEFRA	2007b
Water Metering in Areas of Serious Water Stress	DEFRA	2007c
Climate Change Act	DECC	2008
Future Water – water strategy for England	DEFRA	2008c
Improving Surface Water Drainage	DEFRA	2008d
Private Water Supplies (England) Regulations	DEFRA	2008b
Draft PPS: Eco-towns	DCLG	2008
Water for People and the Environment – water resources strategy for England and Wales	EA	2009
Charging for Household Water and Sewerage Services	DEFRA	2009b
Revision to Building Regulations Part G (sanitation and water efficiency) and Part H (drainage and waste disposal)	DCLG	2009a
Public Understanding of Water Use in the Home	DEFRA	2009c
Flood and Water Management Act	DEFRA	2010

2.2.1 Increased Water Demand

It is apparent that the UK water sector faces an increasing demand for water, due to increased development. This includes significant population growth: the population of the UK is set to rise by approximately 10% over the next 25 years due to a combination of net migration and natural growth (births exceeding deaths) (Reuters, 2009). For a number of years the water sector has followed a ‘twin track’ approach to water resources management, utilising both demand management and resource development to achieve SWM (DEFRA, 2002). In 2001, after the WFD came into force, the Environment Agency in England and Wales (EA) began to implement Catchment Abstraction Management Strategies (CAMS) to facilitate SWM to meet WFD objectives and produced Figure 2.2 and Figure 2.3, revealing that unsustainable regime areas are also areas where demand is highest (Kellagher and Maneiro Franco, 2005).

Within the UK, three main sectors place a demand on water resources; these are the agricultural, industrial and domestic sectors. Agricultural use is generally for spray irrigation, which returns very little to the hydrological system due to evaporation and incorporation into crops (Kellagher and Maneiro Franco, 2005). Industrial users are generally metered and therefore there is some incentive to practise water efficient processes to minimise overheads (DCLG and DEFRA, 2006). In terms of domestic customers however, the UK is unusual in that it is not widely metered and unique in that it utilises a rateable value arrangement based on the size of a dwelling. This entitles a household to use as much water as required for a set charge to the water service provider (WSP), (DCLG and DEFRA, 2006). Unless the dwelling has a meter fitted, there is no fiscal incentive to save water.

Figure 2.4 demonstrates the use of metering by region within the UK. Particularly noteworthy is that the area currently with the highest rateable value, the South West, has the highest metering penetration, which is almost double the national figure. A comparison of PCC and metering penetration across the world reveals that the UK has a PCC similar to many European countries, but the second lowest level of metering (Figure 2.5). As well as fiscal incentives to water consumers, meters can also provide WSPs with better leakage estimates, as the greater number of metered properties within a district metered area (DMA), the more accurate the water balance of a particular water resource zone (WRZ).

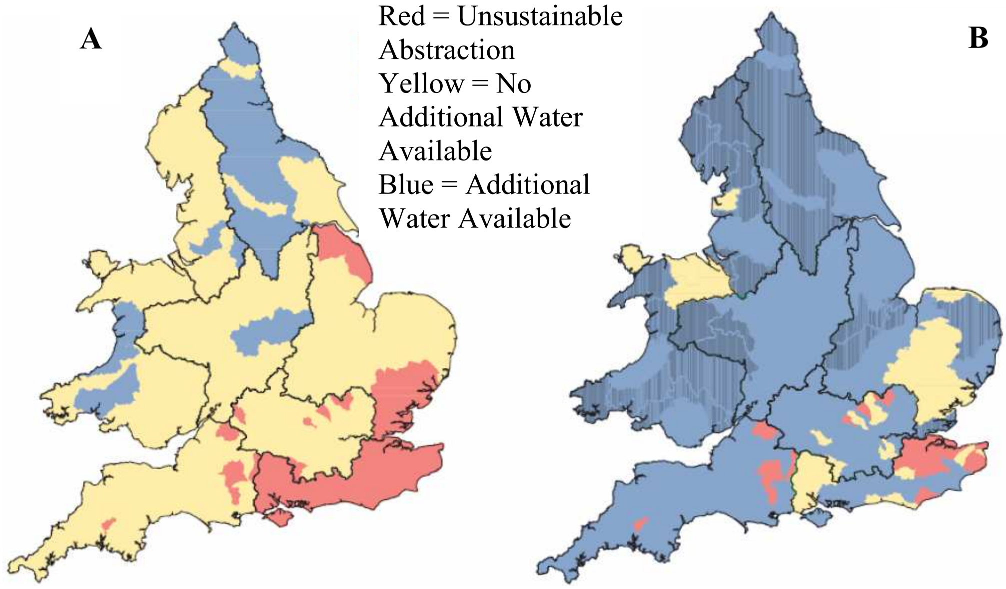


Figure 2.2 Water Availability[1] in England and Wales, Summer (A) and Winter (B) (Kellagher and Maneiro Franco, 2005)

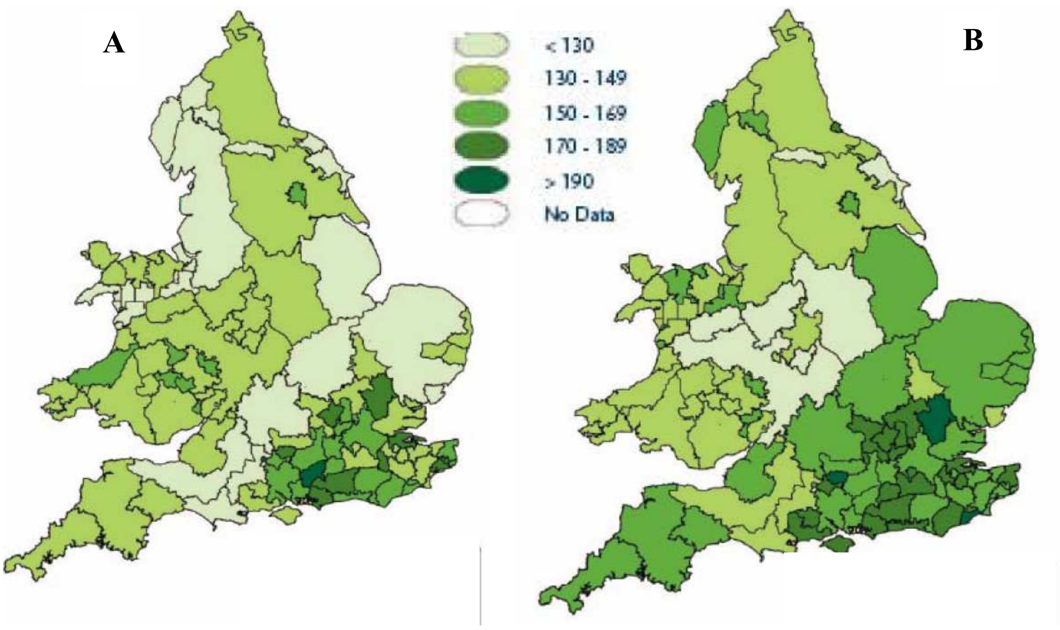


Figure 2.3 Measured (A) and Unmeasured (B) Per Capita Consumption (litres) (Kellagher and Maneiro Franco, 2005)

[1] Water availability is defined as the amount of water available to abstract to meet a required demand level, taking rainfall levels and environmental requirements into account (EA, 2009)

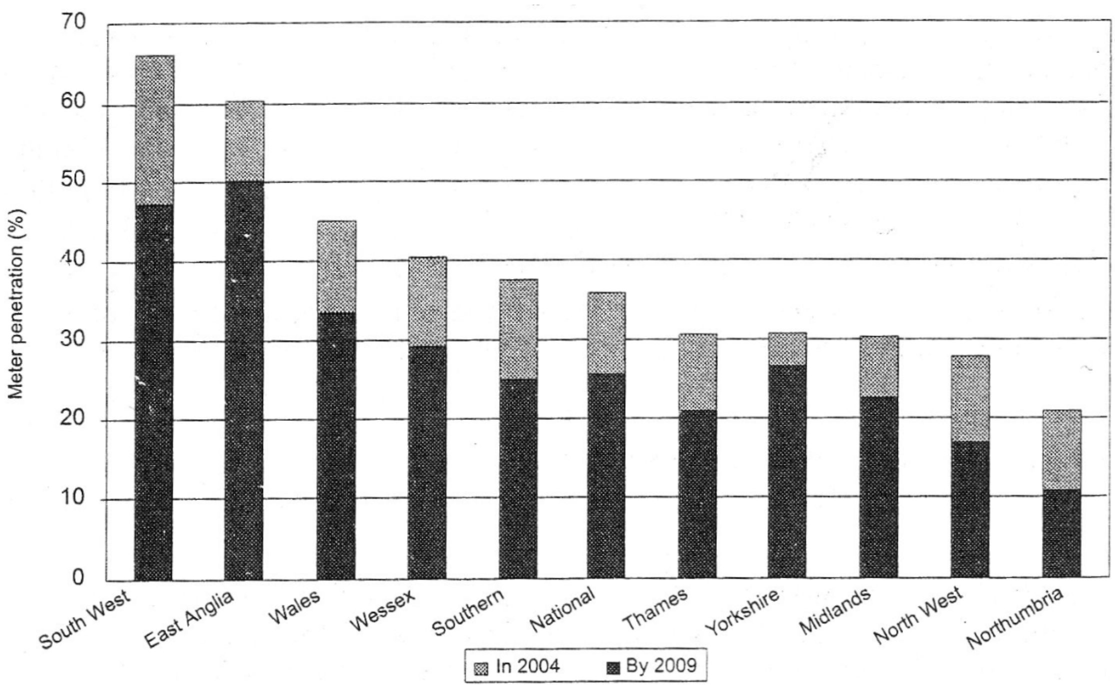


Figure 2.4 UK metering penetration by region (actual, 2004 and projected 2009) (House of Lords, 2007)

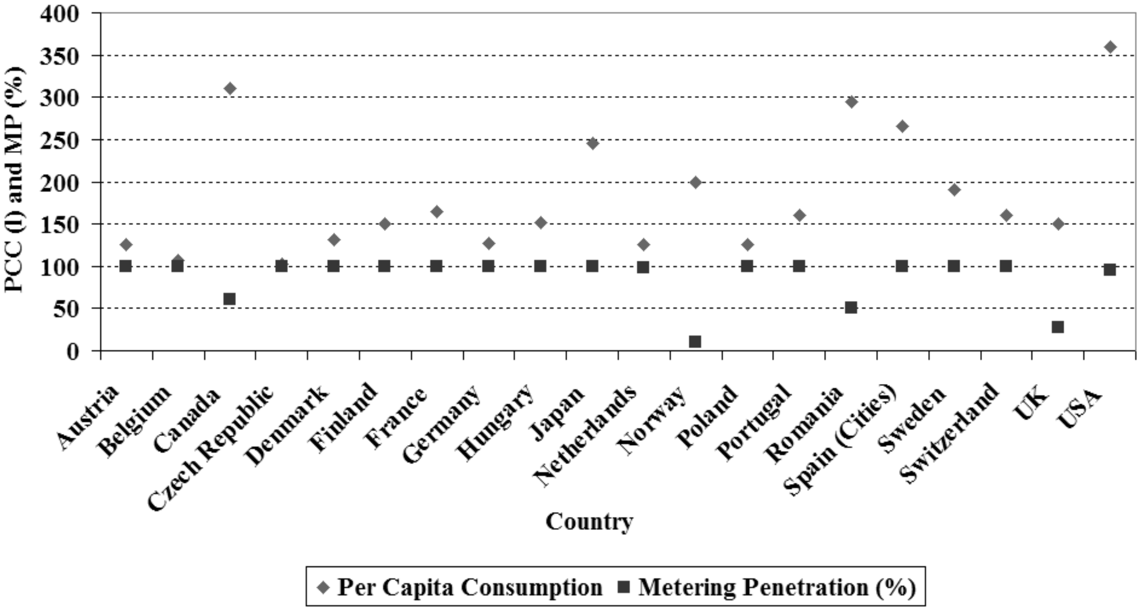


Figure 2.5 Per capita consumption and metering penetration across the globe (data from Waterwise, 2006)

Water consumption in the UK in 2004 was estimated to be approximately 150L per person per day (L/p/d), which is a slight decrease from 2003, but continues an underlying trend of increase (EA, 2005). However, per capita consumption (PCC) in Germany has decreased year-on-year since 1993 (with the exception of 1997). Compromised groundwater resources, demand management activities and the widespread uptake of RWH technologies may have contributed to this declining trend (Konig, 2001). The consumption rates of the two countries are compared in Figure 2.6.

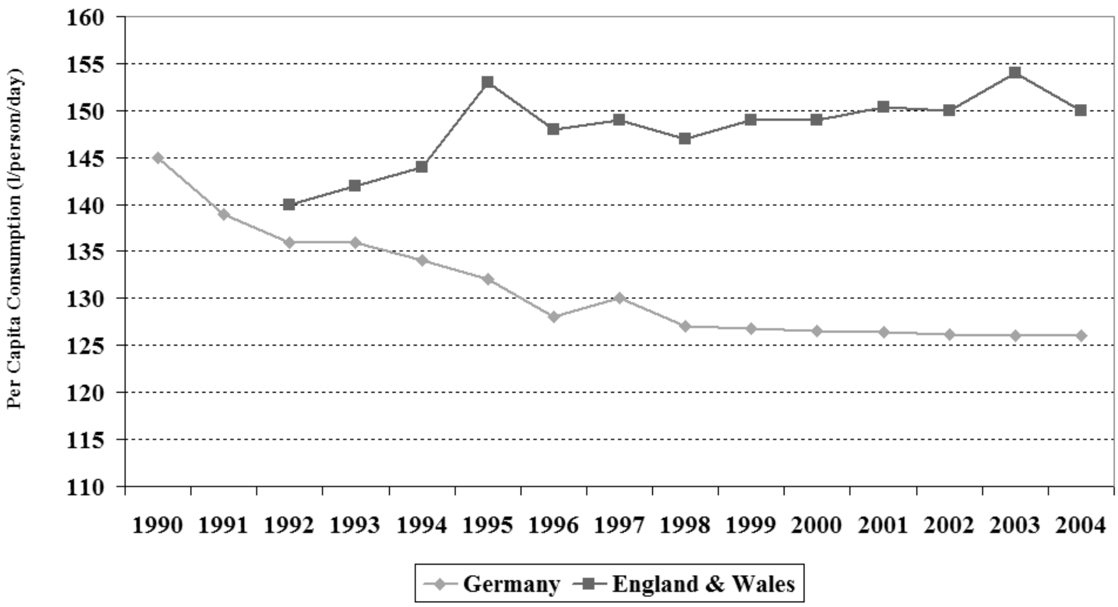


Figure 2.6 Domestic water consumption in England & Wales and Germany (data from Konig, 2001; EA, 2005; Wikipedia, 2007)

PCC in the UK is 55% higher than in 1980, arising from changes in lifestyle such as the increasing use of washing machines, dishwashers, power showers and spa baths (DCLG and DEFRA, 2006). Many WSPs assert that domestic household demand is the only component of total water demand that is increasing (Kellagher and Maneiro Franco, 2005). To address this, WSPs have since 1996, held a statutory duty to promote water efficiency (DCLG and DEFRA, 2006). Additionally, The Water Services Regulation Authority's (OFWAT - the water industry financial regulator in England and Wales) recent water supply and demand policy places a mandatory requirement on WSPs to reduce annual household demand by one litre per day using water efficiency measures during the period 2009 to 2015 (OFWAT, 2008).

Additionally, the Code for Sustainable Homes (CfSH) was introduced in 2006 with the aim of reducing the impact of new domestic buildings. In relation to reducing domestic water consumption, the code utilises a star-based rating system grouping water consumption into six bands. These are summarised in Table 2.2 (DCLG, 2006b). Recent changes to the Building Regulations also now require that the consumption of 'wholesome' water in buildings must not exceed 125 litres/person/day. Wholesome water is defined as "*water complying with the requirements of regulations made under Section 67 (Standards of wholesomeness) of the Water Industry Act 1991*" (DCLG, 2009a). This refers to water from a centralised water distribution system (WDS), that being potable (fit to drink) quality water. As can be seen from Figure 2.6, the figure of 125L is in line with that recently achieved in Germany. Household *patterns* of micro-component consumption between the UK and Germany are remarkably similar, as demonstrated in Figure 2.7. This demonstrates that a reduction in PCC does not necessarily have to mean a compromise in lifestyle choice.

Table 2.2 Water consumption star ratings for PCC/day under the CfSH (DCLG, 2006b)

	Star Rating	Internal Household Potable Consumption (PCC/day)	Measurement Criteria (PCC/day)	Points Awarded
Internal	★	120	≤120	1.5
	★★	120	≤110	3
	★★★	105	≤105	4.5
	★★★★	105	≤90	6
	★★★★★	80	≤80	7.5
External	★★★★★★	80	Rainwater collection	1.5

Water consumed within buildings is defined in terms of micro-components, which include potable uses such as drinking and cooking and potentially non-potable uses such as toilet flushing and clothes washing (Leggett *et al.*, 2001). Figure 2.8 illustrates the micro-component breakdowns for two building types: a household and an office. It can be seen from these Figures that the highest consumption is for micro-components that could use non-potable water, such as WC flushing or washing machine use.

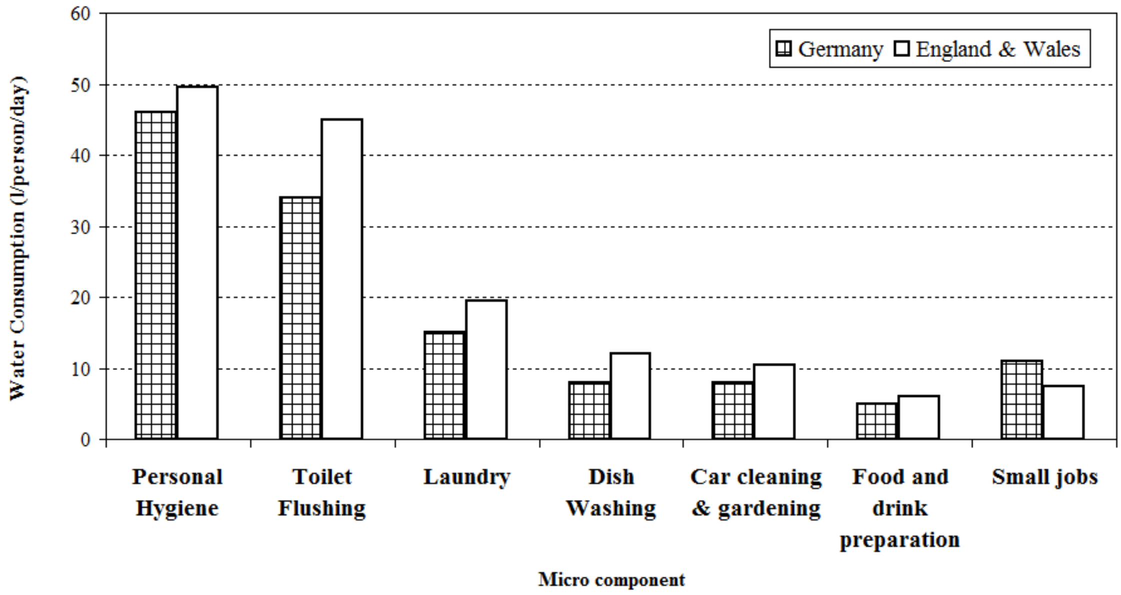


Figure 2.7 Comparison of consumption in England & Wales and Germany (data from Konig, 2001 and Waterwise, 2006)

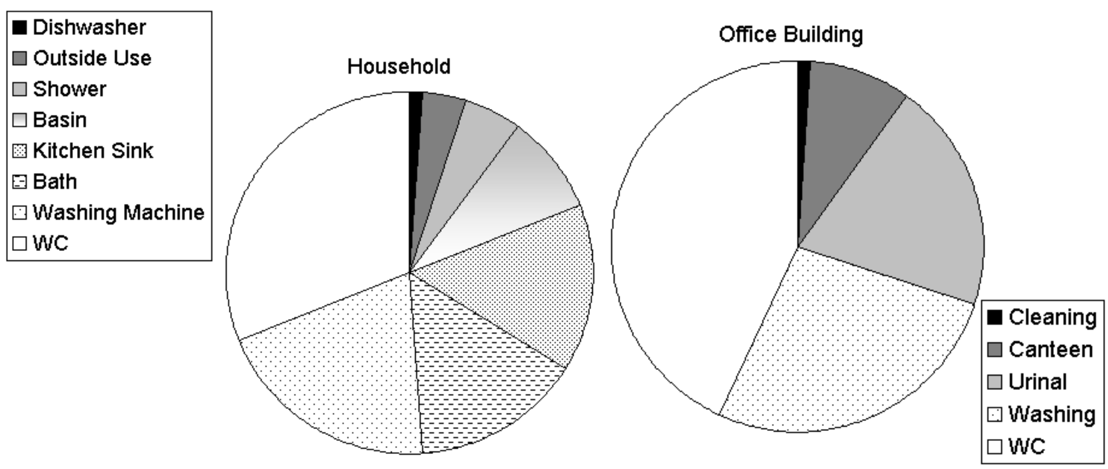


Figure 2.8 Micro-component water use for two building types (adapted from Leggett *et al.*, 2001)

In response to this, water efficiency strategies to reduce consumption in all sectors have been promoted and programmes of action undertaken (Waterwise, 2008). A plethora of water efficiency bodies and schemes have been established, which include:

- Watermark;
- Watersave Network;
- Waterwise e.g. Preston Water Efficiency Initiative, Tap into Savings;

- Water Efficiency Awards (EA).

This also encompasses the inclusion of water efficiency within schemes such as the Building Research Establishment's Environmental Assessment Method (BREEAM, 2007). Key water efficiency initiatives are the installation of water saving devices (WSDs), such as low or dual flush WCs, cistern water displacement devices ('hippo' or 'save-a-flush'), aerator taps and showerheads and the promotion of key messages including 'turn off the tap while you brush your teeth' (Waterwise, 2008).

More recently the link between energy and water has been made, leading to scheme synergies, such as the recently implemented 'Water. Use it. Don't Waste It' campaign from the Government's Act on CO_2 programme, promoted by Envirowise (Envirowise, 2010). This is aimed at a range of stakeholders, including householders and businesses. However, such campaigns presume that consumers' use of water is wasteful (Sefton, 2009). Additionally, they assume that a top-down approach to information provision will result in implementation of the measures described in the information (or advice). Information provision assumes stakeholders are willing and able to act on it once they have received and read it. This is not always the case (Reed, 2009). Furthermore, due to the current focus on environmental issues in the UK, some sectors are beginning to become overwhelmed by the expectation to act. The Tenon Forum (an independent small to medium enterprise (SME) think tank) found that SMEs were cynical about the benefits of going green as they believed the costs of adopting environmentally friendly behaviours outweighed the benefits (Tenon Forum, 2008).

Undoubtedly, adopting water efficiency measures nationwide will reduce demand by a significant amount. However, when the demand reduction limits of such programmes are reached, Hassell (2005) argues other SWM approaches to demand management will be required. The next step will be to more widely incorporate supplementary resources, such as RWH.

2.2.2 Increased Flood Occurrence

Since the 2004/06 drought (which was a 'dry period for most of the country), flooding has rarely been out of the arena of hydrological discussion in the UK (Marsh and Hannaford, 2007; Pitt, 2008; DEFRA, 2009a; Warren, 2010). The 2008 Pitt Review of the devastating floods which swept the country in the summer of 2007 has had widespread impact on the way flood risk is assessed and managed. The review recommended the following areas be addressed:

- Knowing when and where it will flood;
- Reducing the risk of flooding and its impact;
- Being rescued and cared for during an emergency;
- Maintain power and water supplies and protecting essential services;
- Better advice and help to protect families and homes;
- Recovery. (Pitt, 2008)

The UK government has responded by funding a wide range of projects that address these areas. These include increased visibility of and support from the National Flood Forum, the Flood Forecasting Centre (EA and Met Office) and the increased implementation of Catchment Flood Management Plans (CFMPs) and Surface Water Management Plans (SWMPs), (DEFRA, 2009a).

As the focus of this thesis is on RWH and SWM, only the area of recommendation directly of relevance to this will be discussed further, that being reducing the risk of flooding and its impact. In relation to this, one of the primary recommendations from the review was to prioritise adaptation and mitigation responses to extreme weather, including climate change. The review called for a presumption against building in high flood risk areas and the removal of the automatic right to convert front gardens to impermeable surfaces and for new developments to connect surface water drainage to the sewerage system. Additionally, it urged the Government to resolve the issues of ownership and maintenance of SUDS (Pitt, 2008). The recent F&WMA may address the latter, by placing SUDS within the remit of Local Authorities (LAs).

By facilitating a transition to the use of SUDS and other methods to increase permeable areas through which surface water can infiltrate, it is hoped that the localised risk of flooding will be reduced. Additionally, SUDS provide a more adaptable drainage infrastructure than traditional piped systems. This is beneficial as research conducted in 2005 identified the number of flooding incidents from household drainage systems far outnumbered those from public systems and that flood risk could increase by a factor of around 30 times, due to increases in rainfall as a result of climate change (Ashley *et al.,* 2005).

2.2.2.1 SUDS

Conventional drainage systems do not easily regulate runoff quantity and quality and take no account of the amenity or natural recharge values of runoff. Continuing to drain urban areas whilst ignoring wider issues, such as urban flooding, is not sustainable in the long-term (CIRIA, 2000). This is where SUDS come in as they incorporate drainage principles inspired by natural processes. SUDS balance issues of quantity, quality and amenity by dealing with runoff at the source:

- Managing runoff flow rates, reducing urban flooding;
- Protecting and enhancing water quality by natural filtering processes;
- Provide community facilities while addressing environmental needs;
- Encourage groundwater recharge (where appropriate).

This is exemplified by the Surface Water Management Train (SWMT) shown in Figure 2.9. The SWMT promotes the use of sub-catchment strategies in areas that have differing drainage characteristics, in order to reduce the quantity of water being dealt with at any one site. This represents the source control approach, where runoff is dealt with in the location of origin. SUDS operate on the principle that only once all onsite options have been exhausted should water be conveyed elsewhere (the environmental principle of 'subsidarity' – dealing with water where it falls), (CIRIA, 2000). Using appropriate management and construction techniques, retention (aka 'prevention') is used to control the water at the source. There are four main methods of SUDS source control:

- Filter Strips and Swales
- Filter Drains and Permeable Surfaces
- Infiltration Devices
- Basins and Ponds

The SUDS design principle states that systems should aim to ensure that costs do not impose undue external costs on stakeholders, in order to maximise buy-in (CIRIA, 2005). Despite their apparent value, the widespread use of SUDS has received criticism due to the sometimes 'unthinking' way in which they are adopted, as well as a lack of long-term performance data and that this may in fact be a barrier to achieving sustainable drainage systems (Ashley *et al.,* 2008). Putting this debate aside (as it is beyond the scope of this thesis), RWH is often considered a type of SUDS, as it can act as a retention (or detention) basin and can be combined with infiltration devices to maximise source control.

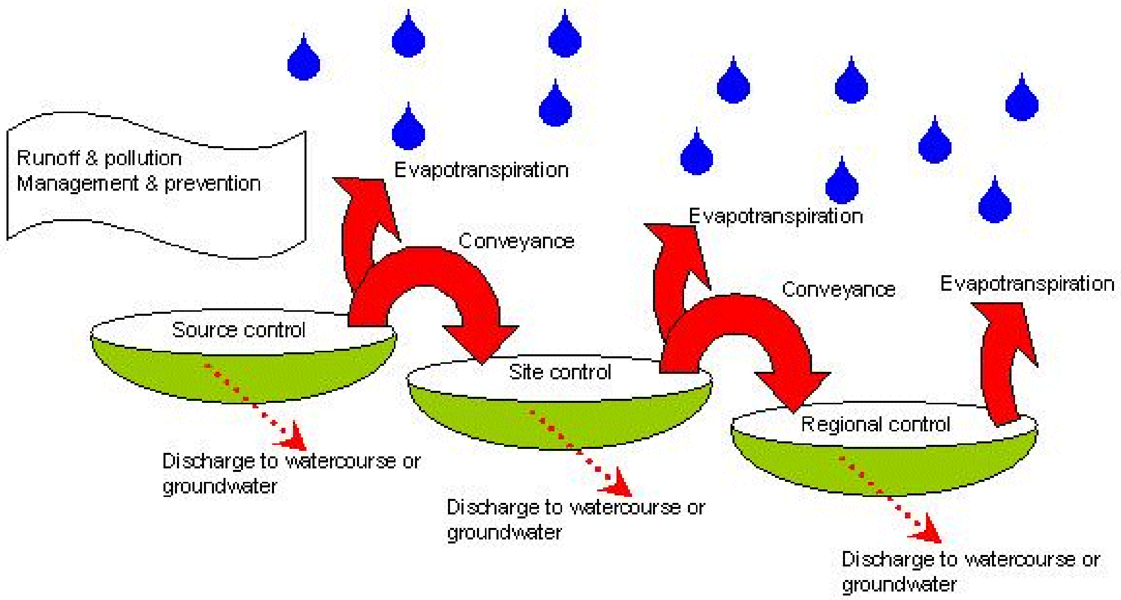


Figure 2.9 The SUDS Surface Water Management Train (CIRIA, 2005)

Therefore RWH is a SWM technique, which has the potential to offer both demand management and source control functionalities.

2.3 RWH as a SWM Technique

RWH at its most rudimentary has been used as a SWM technique for thousands of years as a way of storing water throughout the year, rather than relying on the seasonality of rainfall. The island of Sardinia demonstrates widespread use of cisterns from the 6th century BC, right up to the 19th Century. Cisterns were generally made from stone or terracotta and three distinct types have been identified: ‘bath-tub’ cisterns, which provided 25-134m^3; ‘flask’ cisterns, which supplied 3-250m^3 and ‘cave’ cisterns, which stored in excess of 10,000m^3 (Crasta *et al.*, 1982). The pre-Columbian Maya of the Yucatan peninsula also utilised cisterns, called chultunes, which they used to store water below the ground (Figure 2.10). These were usually capable of storing 30,000L of water and often lined with plaster (Gill, 2000).

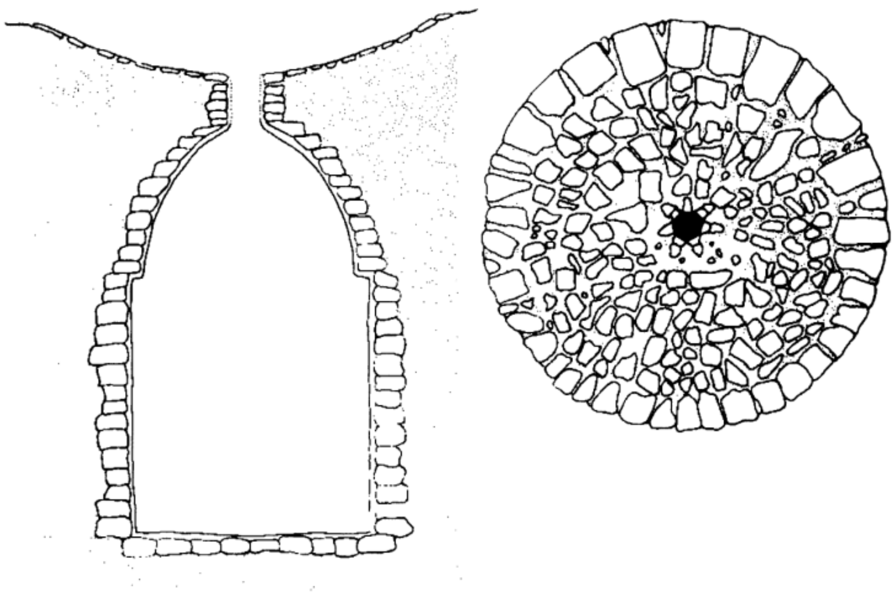


Figure 2.10 Chultun and paved catchment area (Gill, 2000)

RWH is receiving renewed interest as a SWM measure, due to its ability to act as both a demand management and a source control technique (Partzsch, 2009). Mikkelsen *et al.* (1999), in a RWH feasibility study for Copenhagen, emphasised the use of context-appropriate and integrated water management measures, which promoted consideration of a range of sources rather than relying purely on centralised WDS. This highlights the importance of viewing RWH as part of the SWM response. This is further supported by Peters (2006), who makes the case for the consideration of RWH as a context-appropriate part of the SWM approach in Grenada. Consequently, global use of RWH for non-potable applications has significantly increased in the last fifteen to twenty years (Fewkes, 2006).

2.3.1 RWH for Demand Management

As previously established, average PCC in the UK is around 150L per person per day. One third of this drinking-quality water is used for WC flushing/cleansing (DCLG and DEFRA, 2006). Therefore around 50L of high quality, expensively treated potable water is released into the sewerage system to be conveyed back to wastewater treatment plants, where a proportion is retreated and conveyed back to houses. Is it right that we use drinking-quality water to flush the toilet? (Vaes and Berlamont, 1999). As well as WC flushing, RWH is suitable for a range of other non-potable uses, which include urinal flushing, laundry (washing machines), hot water systems and outdoor usage (garden irrigation, vehicle washing) (Roebuck, 2008), as well as fire-fighting and combating the urban heat island affect (Mun *et al.*, 2009). The EA recognises RWH as a way of reducing demand by providing water for domestic uses that do not require drinking quality water (EA, 2008b).

As well as resulting in a reduction in potable water demand, utilisation of RWH to supplement mains water usage can also lead to financial savings for a range of stakeholders (such as building owners). However, such savings are highly variable as they depend on the system/building owner having a meter, the capital and operational cost of the RWH system implemented, the volume of water saved (i.e. the water saving efficiency) and the cost of water and sewerage for the area in which the system is located (EA, 2008b).

A number of small scale UK investigations into the demand management capabilities of RWH have been undertaken and are summarised by Roebuck (2008). These range from irrigation of a golf course, which achieved a 30% reduction in mains water use, to internal and external use at a junior school, which achieved a 77% reduction in mains water usage. Another primary school system achieved only a 37% reduction and an education centre 49%. For domestic properties, the average water saving efficiency was just as variable and estimated between 47% and 57% (Fewkes, 1999a). Chilton *et al.* (1999) conducted an empirical study of a RWH in a commercial building with a large roof in Greenwich, UK, which demonstrated an average water saving efficiency of 21% (across two trials). However, a number of technical difficulties were experienced with the system, such as a faulty valve and a blocked filter.

The most comprehensive study previously conducted on RWH in the UK was the 'Buildings That Save Water' project (Brewer *et al.,* 2001). The study identified that financial savings and water saving efficiencies were variable for a range of building types. For example, for two office buildings water saving efficiencies of 40% and 64% were attained for WC and urinal usage. The payback periods of these systems, however, were significant due to the capital and operational costs of the systems and were estimated to be 267 and 240 years. In contrast, for a housing development of five houses, 100% water saving efficiency was achieved for non-potable uses, with the payback period estimated to be 30 years. Installation problems were experienced with a number of the systems monitored and operational costs were increased due to the need for remedial work to be undertaken (Leggett *et al.,* 2001).

The most recent results from monitoring activity originate from the Preston Water Initiative, which primarily investigated water efficiency, but also undertook the retrofit of a RWH system to a block of 12 flats in Preston, UK (Waterwise, 2009). However, the installation and operation of the system was fraught with problems, such as pump malfunctions and mains top-up issues. This resulted in only a 5.2% overall water saving, at a cost of £30/m^3 and the report concluded that retrofitting should not be recommended due to the issues and costs encountered.

Internationally, the results of similar studies are also highly variable and are summarised in Table 2.3. The studies outlined also reveal that the potential of RWH to meet a level of demand is often estimated using modelling techniques; these will be discussed in more depth in Section 2.3.8. The variability of the water efficiency of these case study systems indicates the highly site-specific nature of RWH for demand management, along with the fact that implementation issues can have a significant impact on system efficiency. With respect to the variability of water saving efficiencies, RWH is receiving increased attention as a stormwater management device, as this has the potential to increase its overall viability.

A final, more recent, example from Australia (Lucas *et al.,* 2010) has demonstrated another possible benefit of utilising RWH: offsetting WDS costs. This had been postulated previously, though few studies had assessed its feasibility. Lucas *et al.,* model a business as usual (BAU) scenario representing no demand management measures as well as two other scenarios, being demand management only and demand management with RWH, respectively. They identify using a model (PURRS – refer to Section 2.3.8), for a case study area in Melbourne, using demand management measures only slightly reduced the peak demand (most likely due to the parallel timing of appliance use). In contrast the use of RWH completely smoothed the peak *mains* water use demand of a domestic building, though the *total* water use of the building retained its classic domestic profile (Figure 2.18, Section 2.3.7).

Further modelling work revealed a significant impact on the cost of the WDS design, as a reduced peak demand required lower pressures and smaller pipe diameters to meet the overall demand of the study area. It was also demonstrated that the use of RWH preserved the minimum pressure required for fire fighting during peak periods, without increasing the pressure to the network (Lucas *et al.,* 2010). Although this study utilised a diurnal domestic demand profile to produce outputs at 6-minute resolution, the primary limitation is that it only investigated domestic buildings. A commercial or industrial development, for example, would perhaps demonstrate a different diurnal demand pattern for both RWH and mains water consumption. This is discussed in depth in Chapter 6.

Table 2.3 Summary of studies into assessing the efficiency of RWH systems

Location of Study/System type	Water Saving (%) Actual (a) or Estimate (e)	Reference
Hilly communities of Taipei, Taiwan/cylindrical stainless steel tanks	21.6 a	Chiu *et al.,* 2009
Beijing, China/urban domestic	25 e	Zhang *et al.,* 2009
Eco-housing development, Daegu, Korea/communal 180m^3 tank	65 e	Kim *et al.,* 2007
Berlin, Germany/urban domestic	70 a	Nolde, 2007
Brazil/urban domestic	48-100 e (depending on region)	Ghisi, 2006
Various, Australia	6-74 e (depending on region)	Coombes and Kuczera, 2003
Tokyo, Japan/Stadium	59 a	Zaizen *et al.,* 1999

2.3.2 RWH for Stormwater Management (SM)

Vaes and Berlamont (1999) assert that implementation of RWH systems could have wider applications than just saving water and Kinkade-Levario (2003) claims that RWH represents significant potential for eliminating or mitigating the root cause of development-generated impacts at the source. Konig (2001) and Kellagher and Maneiro Franco (2005) reinforce these assertions, summarising that decentralised RWH can facilitate:

- Reducing loads on sewers;

- Reducing pollution to surface waters;
- Improving urban climate and landscape;
- Increasing groundwater supplies;
- Reducing individual process or operating costs.

In many countries stormwater is traditionally collected and transported via drainage pipes which can be separate from or combined with the foul sewer system. The latter incorporates ‘combined sewer overflows’ (CSOs), which discharge if the capacity of the sewer is exceeded. If two severe storms happen in quick succession, the antecedent rainfall from the first may still reside in the combined sewer and if the volume of runoff exceeds its capacity flooding occurs (Vaes and Berlamont, 2001). Therefore this approach is receiving growing criticism due to increased incidents of costly urban flooding, runoff being an increasing source of pollution and the popularisation of source control measures, SUDS and best management practices (BMPs) (Martin *et al.*, 2007b; Astebøl *et al.*, 2004; Tsihrintzis and Hamid, 1997).

Reconsideration of the drainage capacity of sewers is currently occurring in the UK, though not just due to climate change; the historic drainage network and CSOs are increasingly being overwhelmed due to expanding urban development creating additional runoff. For this very reason, many countries already disconnect or are considering disconnecting impervious areas from drainage facilities (Waters *et al.,* 2003; Pitt, 2008). In Germany, householders do not pay a set drainage charge; the charge is calculated based on the volume of water exported to drainage. This provides the homeowner with an incentive to utilise the runoff on site, which usually takes the form of RWH systems (Kellagher and Maneiro Franco, 2005).

Vaes and Berlamont (1999) demonstrated the impact of RWH on CSO emissions using a modelling approach. Results from simulations revealed that storage in tanks produced a reduced storage in the CSO, with peak discharges being reduced by 15-25% – demonstrating that RWH could have an impact on CSOs. It was also demonstrated that observed impacts were significantly enhanced for higher consumption rates i.e. when the tank was emptied more regularly. A seasonal effect was also identified, as the occurrence of completely full tanks was lower in summer than in the winter. Therefore there was an increased availability of larger storage volumes for high intensity summer rainfall events.

Vaes and Berlamont (2001) extended the study to examine the effect of RWH on design storms. Composite design storms, which include all storm durations of a particular return period, can be used to design CSO systems using rainfall intensity-duration-frequency (IDF) calculations. Additional parameters were introduced into the model to represent extreme rainfall values. Results showed that composite storm peaks were reduced, as demonstrated in Figure 2.11, where the peak of a 5-year return period is reduced to the peak of a 1-year return period design storm.

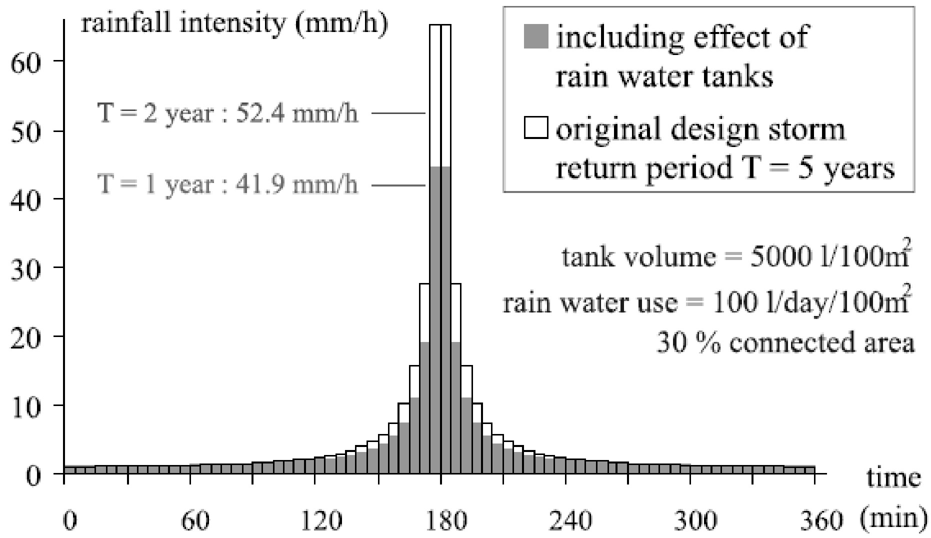


Figure 2.11 Effect of RWH on Design Storm Peak Volume (Vaes and Berlamont, 2001)

A further investigation by Kellagher and Maneiro Franco (2005), also examined the impact of RWH on extreme events, emphasising that until detailed information exists a precautionary position should be assumed. Storage capacities of 0.75 and 1.5m ^{3}/person were examined, for a roof-catchment-only area of 20m² per person and demand rates of 25, 50 and 100L PCC/day. It was shown that a storage system could reduce peak flows by up to 55%. A 1.5m ^{3}/person tank provided a more reliable peak flow reduction for rainfall events over 60mm, reinforcing that excess storage from a RWH supply perspective is not necessarily undesirable. For extreme-extreme events (rainfall >150mm) there was no peak flow reduction attributable to RWH. However, it was found that if storage alleviated the maximum rainfall peak for an event, any subsequent peak rainfall event would generate the largest overflow emission. Similar patterns were noticed for runoff volume reductions, as would be expected.

More recent work conducted in the Asian context demonstrated the potential of RWH for reducing the impact of a development on runoff from the site. Kim *et al.* (2007) used a modelling approach to examine the impact of an eco-housing complex in Korea. Results showed that the average estimated surface runoff before development was 62.72 m^3/day, after development was 188.27 m^3/day and after development with RWH and infiltration facilities was 97.38 m^3/day. Other research using Seoul City as a case study also applied a modelling approach to estimating the potential impact of RWH on controlling sewer flooding (Kim and Han, 2006). Application of the 'Rainfall-Storage-Drain' (RSD) model identified that RWH could control the rooftop peak runoff for a 10 or 20 year frequency rainfall event, reducing the 30 year rainfall event peak flow to that of a 10 year rainfall event.

Parkinson *et al*. (2007) in the UK context modelled the impact of a range of demand management measures on the flow and water quality of the sewer system. The model was calibrated using flow and quality data from a case study residential development in Manchester. Conventional and low-flush WCs and RWH and GWR for WC flushing were assessed for their impact on CSO frequency and contribution to sewer sedimentation rates, as well as on reducing water consumption. Results showed that although the WSDs yielded the highest water saving, RWH was the only technique to show multiple benefits as well as water saving, which included a significant reduction in CSO discharges and a reduction in sewer sedimentation rates.

An additional study by Memon *et al.* (2009) in the UK context identified that the use of RWH systems could potentially provide a reduction of approximately 50 % in peak flows entering the combined sewer for a range of investigated storm events. The estimated reduction in peak runoff was considerably higher in cases where storm events occurred after the peak demand for non-potable water (i.e. when the RWH storage tank had just met a significant demand). In agreement with Kellagher and Maneiro Franco (2005) the work highlighted that RWH systems may provide the greatest stormwater control potential for low to medium depth rainfall events. However, it was also asserted that utilising water efficient appliances in conjunction with RWH would result in satisfying the non-potable demand for a longer period but at the cost of increasing flows in sewers and overflow from the RWH tank.

In summary, it is possible that in urban areas where relatively frequent flooding events occur, retrofitting with RWH could provide a level of protection from stormwater runoff. However, further research is needed to incorporate other runoff generating surfaces besides roofs and to examine the impact of the supply-demand balance of a range of building types on storage capabilities (Kellagher and Maneiro Franco, 2005). Unfortunately, despite the number of modelling studies described, there remains a deficit in *empirical* research into the impact of RWH as a SM measure, which contributes to the barriers to RWH – discussed in more depth in Section 2.3.10.

2.3.3 RWH for Demand *and* Stormwater Management

The contemporary discrepancy between the demand placed on WDS and the excesses generated by combined sewerage systems has not gone unrecognised (Vaes and Berlamont, 1999; Osman Akan and Houghtalen, 2003). A number of developing and developed countries have identified that stormwater could be useful as a local water supply, rather than just seen as a local problem and are therefore promoting the use of RWH to achieve both demand management and source control goals (Coombes *et al.*, 1999; Konig, 2001; Handia *et al.,* 2003; Waters *et al.,* 2003; Peters, 2006; Van der Sterren *et al.,* 2007; Ward *et al.,* 2010b; White, 2009). Several studies have measured and modelled these benefits.

Chu and Fok (1991) assert that storm drainage system peak capacities are expensive to increase when accommodating new urban development. They cite an example from the USA, where increasing urbanisation of foothills in Denver, Colorado, had resulted in increased runoff in excess of the existing systems' capacity. RWH was made compulsory in certain developments, to prevent storm drains becoming overloaded and the water was utilised for non-potable demand, such as lawn irrigation and car washing.

As part of the Australian Governments' 'Build Better Cities' programme launched in 1995, many states and cities have launched an Environment Management Plan. Built under this programme, Figtree place is a WSUD located within Hamilton, an inner suburb of Newcastle, NSW, Australia. Constructed on a remediated bus terminal, it consists of 27 residential units using RWH (for non-potable uses), infiltration trenches and a central basin where cleansed stormwater recharges an unconfined aquifer (Coombes *et al.*, 2002), with source control being its primary objective. This on-site detention and retention approach was also undertaken on redeveloped properties in Greater Western Sydney (Van der Sterren *et al.,* 2007).

A similar approach has been demonstrated in the Puget Sound area of Seattle, where 302 ML/d of potable water is supplied annually, yet on average 605 ML/d of unused stormwater is pumped into the Puget Sound. In April 2002, the city of Seattle adopted Resolution 30454 on wastewater reuse and rainwater reclamation. This aims to facilitate water resource management and reduce stormwater runoff, using source control in the form of RWH in a domestic setting (Moddemeyer *et al.*, 2003; McCann, 2007).

Handia *et al.* (2003) reinforces rainwater runoff as a resource to be harnessed and used. Rainwater is seen as a problem in Lusaka, urban Zambia, where poor drainage results in frequent local flooding. However, annual average consumption is around 73million m^3, whilst 306million m^3 falls on the city and is piped away as 'a nuisance'.

RWH is being used in a similar context in Asia, where tackling monsoon rainfall has led to a new approach to stormwater management in urban Seoul, Korea and Sumida City (Tokyo), Japan. High costs of large storm drains and sewers, along with associated construction disruptions and periods of shortage, led to a shift towards a more integrated approach. Currently, regulation requires RWH storage facilities in all new public buildings and as a priority in large new developments, which is reinforced by a personal and intensive demonstrative publicity and promotion campaign (Han, 2009 and Murase, 2009). In response to an increased demand for RWH innovative RWH storage techniques are being trialled in many Asian countries, such as the 'plastic bag', illustrated in Figure 2.12 (Dao *et al.*, 2009). Such techniques contrast to the conventional underground rigid-tank systems fitted in the UK (Ward *et al.*, 2010a).

Figure 2.12 Innovative 'plastic bag' RWH system used in Asia (Dao *et al.*, 2009)

2.3.4 RWH System Types

Herrmann and Schmida (1999) and Leggett *et al.* (2001) categorise RWH systems by their hydraulic properties and pump type, respectively. Table 2.4 and Table 2.5 summarise these types, along with diagrams of their configurations.

The diagrams in Table 2.4 and Table 2.5 illustrate the most conventional location of the RWH main storage tank currently considered in the UK, that being underground (Hassell, 2005). This location is often promoted as a means of aiding water quality by providing a cool environment in which sunlight-induced algal growth is minimised (Fewkes, 2006). However, in some climates where space is adequate, the tank is often located in a basement or above ground (Figure 2.13), thus reducing ground excavation costs (Thomas, 2006). Rarely is the main storage tank located in the roof space of a building, due to the extra loading requirements, which *may* necessitate costly structural reinforcements (Hauber-Davidson, 2007). Some advantages and disadvantages of below and above ground tanks are summarised in Table 2.6.

Figure 2.13 Basement and above ground RWH tanks in Australia (Hauber-Davidson, 2007; Waterwall, 2009)

Table 2.4 Hydraulic configurations for RWH Systems (Compiled from Herrmann & Schmida, 1999)

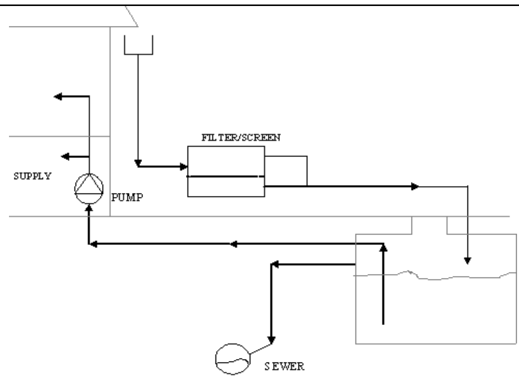
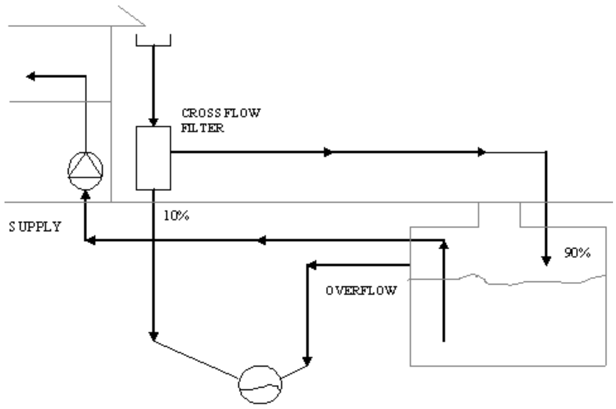
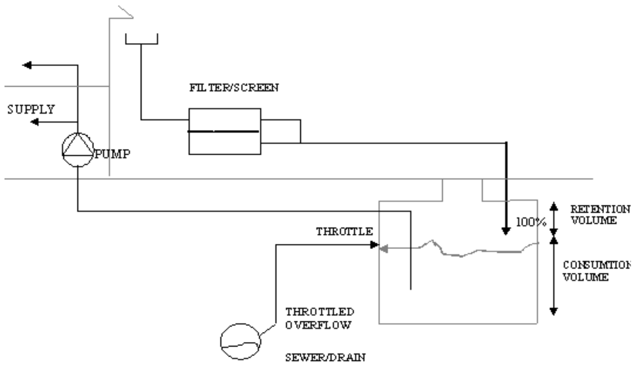
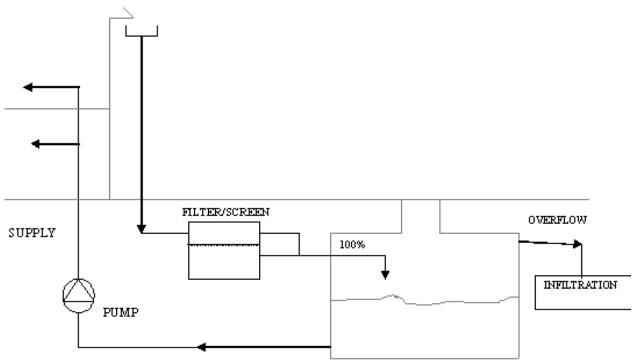
Type	Hydraulic Configuration	Diagram
Total Flow	Filter designed so pipework upstream does not surcharge if blockage occurs	
Diverter	Volume collected dependent on the flow rate in the collection pipe	
Retention and Throttle	A 'retention' volume is released slowly via throttle valve to sewers	
Infiltration	Overflow infiltrates into ground	

Table 2.5 Pumping configurations for RWH Systems (Compiled from Leggett *et al.,* 2001)

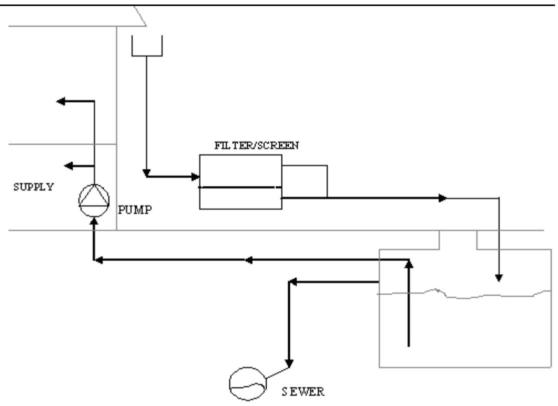
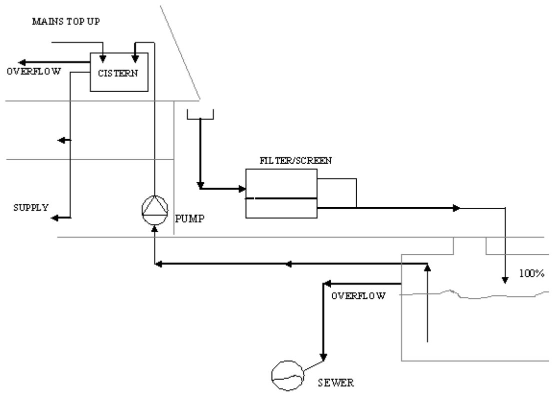
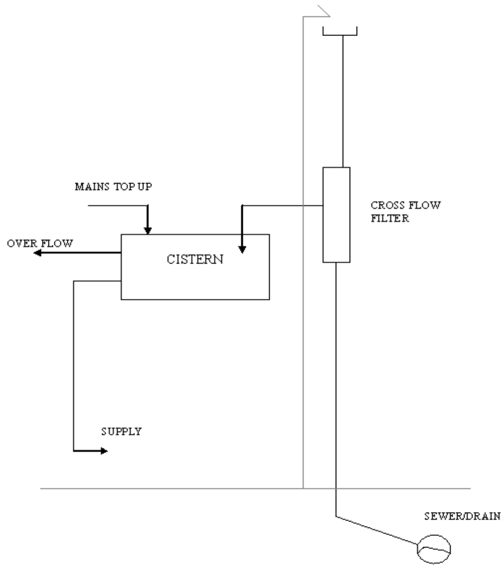
<table>
<tr><th>Type</th><th>Pump Type</th><th>Diagram</th></tr>
<tr><td>Directly Pumped</td><td>RW pumped directly from storage tank to appliances</td><td>
</td></tr>
<tr><td>Indirectly Pumped</td><td>RW pumped from storage tank to header tank, then gravity fed into supply</td><td>
</td></tr>
<tr><td>Gravity Fed</td><td>Storage tank located in roof space, supply provided via gravity</td><td>
</td></tr>
</table>

Table 2.6 Advantages and disadvantages of above ground and below ground RWH storage (modified from Thomas, 2006)

	Advantage	Disadvantage
Above Ground	Easier inspection	Requires space
	Facilitates gravity extraction	Easier to damage
	Increased pressure potential	Exposed to weather
		Dangerous if fails
Below Ground	Ground provides support	Extraction requires a pump
	Unobtrusive	Reduced leak detection
	Reduced temperatures	Risk of damage from roots/rising groundwater
	Space not generally an issue	Must ensure vehicle loading is accommodated
		Buoyancy if not adequately backfilled

2.3.5 Conventional RWH System Components

Conventional RWH systems, as outlined in the previous sub-section, are generally installed in buildings to collect runoff from rooftop catchments. Other catchment areas, such as roads and car parks or other impermeable surfaces can be used, but these are susceptible to a wider range of pollutants which have the capacity to produce a lower quality of runoff (Davis *et al.,* 2001; Nolde, 2007). Rooftops are not without their sources of contamination, but a certain level of control of inputs is possible (Spinks *et al.,* 2003). Conventional rooftop RWH systems consist of a range of building and system-related components, which are summarised and briefly described in Table 2.7.

The use of conventional system designs and components is well established in a number of countries including Japan, Australia and Germany. For the latter, it is estimated that 50,000 systems are being installed annually, mostly in new houses for WC flushing and garden and laundry use (Nolde, 2007). However, as interest in RWH has increased so has the need for a range of system types for a wider range of site characteristic, as well as having increased adaptability in the face of potential climate change impacts and lower energy requirements to reduce carbon dioxide (CO_2) emissions (EA, 2010).

Table 2.7 Summary and description of conventional RWH system components (Compiled from Leggett *et al.,* 2001; Still and Thomas, 2003; Wu *et al.,* 2003; Arthur and Wright, 2005; Fewkes, 2006; BSI, 2009; Ward *et al.,* 2010b)

Component	Function	Description
Catchment (collection area)	Produces runoff as function of size, material, slope, roughness, wind	Materials range from slate to grass (green roofs)
First flush device	Diverts a portion of runoff away from conveyance and storage (see Section 2.3.9.1)	Used to varying degrees in different countries; Not included in the UK British Standard (see page 226)
Conveyance	Runoff capture and transmission to storage - efficiency can depend on shape and slope	Guttering and downpipe operating conventional or siphonic drainage
Filters	Removal of coarse and fine debris/contaminants from conveyed RW	Pre-tank crossflow or vortex, floating suction (on the pump), inline backwashing
Disinfection	Water treatment	Chemical; UV
Storage tank	Retain runoff (harvested rainwater), due to irregularity of rainfall/demand, for subsequent use or release. Act as water quality buffers by facilitating sedimentation/biofilm processes	Materials include concrete, brick, steel, glass reinforced plastic (GRP), high density polyethylene (HDPE). Size/cost varies depending on supply-demand balance of site
Pump	Convey RW from storage to header tank or point of use	Usually submersible, lifespan of approximately 5-10 years
Header Tank	Holding tank located in roof space for gravity feed to points of use	Feed operated by low and high level float switches, mains top-up feeds into header
Control panel (optional)	Centralises electrical system controls (e.g. float switches) and operation indicator lights	Indicates system malfunction, lifespan of 15-20 years
Pipework Valves	Internal building distribution and control	Plastic pipes, solenoid valves for RW/mains top-up control

2.3.5.1 Energy Consumption

Sources of operational energy in a RWH include the pump, control panel and solenoid valve. Previous studies (Dixon, 2000; Roebuck, 2008) have utilised simple equations to calculate RWH system pump energy consumption in order to calculate system operating costs. However, these studies did not quantify CO_2 emissions. Additionally, they did not consider the efficiency of the pump, or incorporate parameters to distinguish between pump start-up and pump operating energy consumption. Further consideration is given to this in Chapter 6, which describes an improved method for calculating operational energy consumption. Innovation in RWH system design could help reduce the impact of emissions from RWH systems.

2.3.6 Innovative and Experimental RWH Systems

As previously mentioned, the plastic bag RWH storage device is being experimented with in Asia, where space constraints prevent installation of a more conventional tank. The components of the RWH system itself (Figure 2.14) are less resource-intensive than conventional systems, although the building-related components, such as guttering, downpipes and internal pipework are similar. The system is modular and storage capacity can be increased by interconnecting a series of bags (Dao *et al.*, 2009).

Figure 2.14 Components of the innovative 'plastic bag' RWH system (Dao *et al.*, 2009)

An experimental system on trial in Australia, combining stormwater treatment and water supply, is that of the 'ENVISS Sentinel 450' (Poelsma *et al.,* 2009). The system consists of porous pavements situated atop polyvinyl chloride (PVC) stormwater pits containing sediment traps and filters (Figure 2.15). A drainage layer then conveys outflow to underground storage tanks, from where it is reused in a school for WC flushing or field irrigation. Preliminary results indicate the system is effective at removing sediment, nutrients and heavy metals and estimates suggest it will supply 69% of the school's non-potable water use (Poelsma *et al.,* 2009).

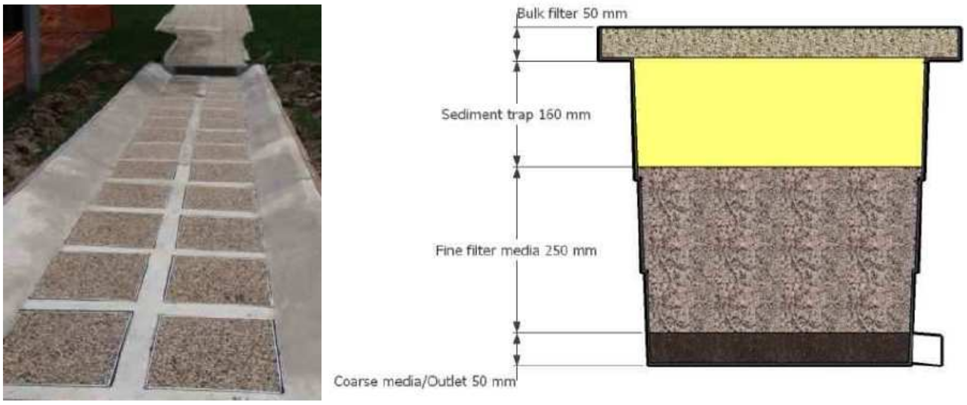


Figure 2.15 External view and cross-section of the ENVISS Sentinel 450 system (Poelsma *et al.,* 2009)

Another innovative Australian RWH system is the rainwater storage gutter system, which utilises the space in specially formed gutters to store runoff (Hardie, 2010) and is illustrated in Figure 2.16. The system combines storage with overflow-infiltration and is beneficial when plot size restricts the use of conventional storage tanks. Additionally, the system is gravity fed, therefore reducing pumping energy requirements and costs. The gutters are available in a range of sizes and are designed to be supported by the roof frame, but can also be supported by the external wall; therefore consideration needs to be given to this when considering its implementation (Hardie, 2010).

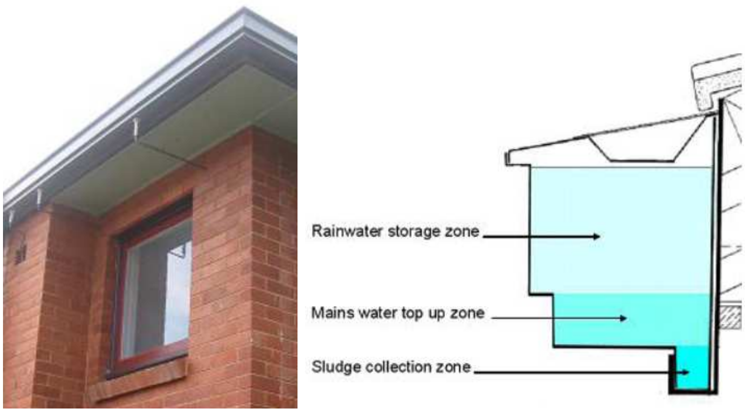


Figure 2.16 External view and cross-section of the 'gutter' storage RWH system (Hardie, 2010)

In the UK, the conventional system is currently dominant, as the UK RWH market is in its infancy and knowledge gathering activities have predominantly focused on Germany and Australia, where use of this type of system has been widespread (DTI, 2006). However, an experimental system has been developed by a partnership between Welsh Water and Aqualogic (Wherlock, 2009), which is illustrated in Figure 2.17. The 'ARC' (Aqualogic Rainwater Collection) system is retrofittable and gravity fed, therefore it demonstrates adaptability and reduced operational energy requirements and costs. The system collects 100L of water, has a mains top-up, has no mechanical components and is modular, facilitating the ability to increase capacity. However, the system currently suffers from aesthetic and potential structural loading issues (depending on the number of connected units). It has undergone a harvested water quality study, which identified that the health risk posed by using water from the system was low (Fewtrell *et al.,* 2009).

Figure 2.17 The 'ARC' RWH system under development in the UK (Wherlock, 2009)

Whether considering conventional or innovative systems, the primary component that has to be designed to suit a particular building's supply-demand requirements is the storage tank (Fewkes, 1999a). Coincidentally, this is also usually the largest and most costly part of the RWH system and therefore there is a significant incentive to optimise its size (Chu *et al.,* 1999).

2.3.7 RWH System Tank Sizing

Often cost-benefit analysis and pay-back periods are central to the decision to install a RWH system, whether domestic or commercial. Therefore unless significant sustainability drivers exist, water must usually be supplied at the lowest cost (Liaw and Tsai, 2004). As well as cost, the size of a storage tank influences:

- volume of water conserved - system performance and efficiency;
- system installation costs – payback periods;
- retention time - water quality;
- frequency of overflow - water quality;
- volume of overflow – flood management affectivity.

(Fewkes and Butler, 2000)

Determining a suitable tank size for a particular site is not straightforward, as both rainfall and demand are stochastic (Ngigi, 1999). Two types of tank size were identified by Fewkes and Butler (2000):

- Large-volume stores – conserve ≥ 95% of household water and significantly reduce flows to the sewer system;
- Small-volume stores – conserve ≤ 50% of household water and have a less significant impact on reducing flows to the sewer system.

Despite small stores offering a range of advantages, such as low cost, ease of implementation and short retention times (to aid water quality), the tendency in practice has been to use simple models that result in large-volume stores potentially yielding a high degree of reliability (Fewkes and Butler, 2000). In contrast to practice, a substantial volume of academic research has been undertaken in the area of RWH system modelling for tank sizing and design.

A number of approaches and their associated methods are well established for the sizing of RWH tanks, these are summarised in Table 2.8. The most frequently utilised method is the behavioural approach. More detail is provided regarding the method developed by Fewkes (1999b) in Chapter 6, as this Chapter utilises application of a tool based on this method. A number of detailed computer-based modelling tools based on the summarised methods, capable of simulating RWH system design and/or performance, have been developed.

Although RWH systems can be implemented within any building type, the majority of the studies reviewed were conducted on domestic systems. Reasons for this may include access to monitoring data and the availability of demand data. The diurnal profile of domestic water consumption for the previously discussed micro-components is well established (Figure 2.18). However, the same cannot be said of data for non-domestic buildings, which limits the estimation of the demand for these building types. This is a severe limitation in designing a RWH system, as too large a demand may result in a low water saving efficiency resulting in a larger tank and longer payback period, whereas too small a demand may result in a small tank that cannot satisfy demand resulting in more mains water being used.

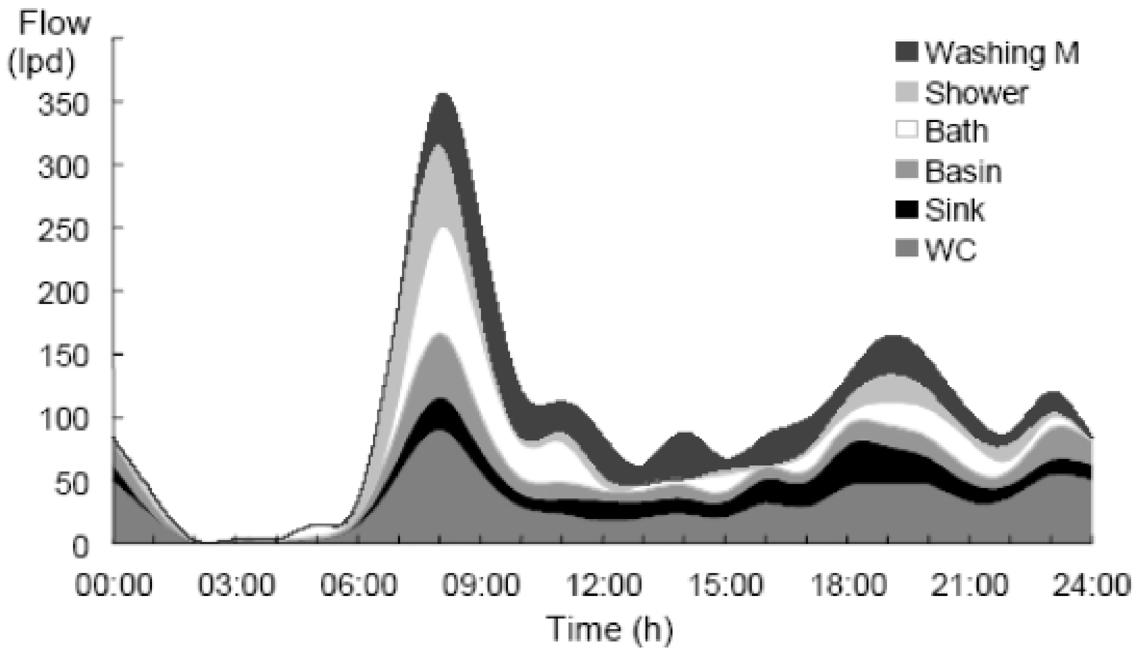


Figure 2.18 Domestic micro-component diurnal wastewater discharge profile (Butler and Davies, 2004)

Table 2.8 Summary of RWH system sizing methods

Approach	Method	Description	References
Moran		Equates tank design to a reservoir problem, using simultaneous equations (based on queuing theory)	Ikebuchi and Furukawa (1982)
Critical period	Mass curve	Set of curves produced using rainfall and demand data, can include use of statistical method, best for initial designs	Schiller and Latham (1982); Fewkes (1999b); Gould and Nissen-Peterson (1999); Ngigi (1999); Liaw and Tsai (2004); Peters (2007)
	Probabilistic frequency analysis	Sequential peak algorithm used with rainfall and demand data	Lee *et al.* (2000)
	Behavioural analysis	Continuous mass storage equations to simulate time-variable in/outflows to determine reservoir storage quantity, different rainfall resolutions can be utilised	Jenkins *et al.* (1978); Schiller and Latham (1982); Latham (1983); Appan (2000); Chu *et al.* (1999); Dixon *et al.* (1999); Fewkes and Butler (2000); Srivastava (2001); Cheng *et al.* (2006); Mitchell *et al.* (2007)

2.3.8 RWH System Sizing Tools

Zoppou (2001) and Elliott & Trowsdale (2007) have produced detailed reviews of a range of RWH and urban stormwater drainage modelling tools. Those of most relevance to RWH are summarised in Table 2.9. Elliott and Trowsdale (2007) highlight the need for the development of both simple and sophisticated models, along with greater application and *testing* of existing models, in order to address gaps in research and knowledge. Several of the models summarised are either freely available or available to purchase. However, rarely do UK-based non-academic stakeholders utilise such tools, due to an apparent lack of awareness of the availability and capabilities of these tools (Ward *et al.,* 2010b) (see Section 4.4.1).

Complex continuous simulation modelling tools do exist within the UK. For example, the Urban Water Optioneering Tool (UWOT) (Liu *et al.*, 2006), permits quantitative and qualitative assessment of a range of alternative water management options. These include water efficient appliances, RWH, grey water reuse, SUDS and other decentralised technologies, across a range of spatial and temporal scales. The tool has been developed in Simulink and uses data inputs from an Excel-based user-interface to execute analyses via a DLL file. Technology selection is facilitated by the use of a multi-objective genetic algorithm. UWOT has been utilised to assess technologies in terms of a range of sustainability indicators (environmental, economic, social and technical), as well as to evaluate the inclusion of such technologies within the Elvetham Heath development in the UK (Makropoulos *et al.*, 2008).

The RainCycle tool is RWH-specific and represents the state-of-the-art in UK-based system design (Roebuck and Ashley, 2007). The tool is Excel/Visual Basic-based and freely accessible via the internet. It simulates the hydraulic and financial aspects of RWH systems for a chosen tank size. Functions permit optimisation of the tank size for a particular catchment size and a particular level of demand. Roebuck (2008) applied RainCycle to a range of case study RWH systems in buildings of differing scales and identified that water saving efficiencies and payback periods were variable.

Within the Australian water industry, two main modelling tools are currently utilised to assess RWH systems and other stormwater management practices – PURRS and MUSIC. The Probabilistic Urban Rainwater and wastewater Reuse Simulator (PURRS) is a behavioural model developed to evaluate the detailed design of source control strategies such as RWH tanks and OSD (on-site detention) facilities (Coombes and Kuczera, 2001). In terms of RWH, the model simulates system performance and assesses storage tank sizes. Rainfall is simulated by a pluvio rainfall generator, when data is available, or by generating synthetic data using DRIP (Disaggregated Rectangular Intensity Pulse) when real data is unavailable (Coombes and Kuczera, 2003).

Table 2.9 Existing models for analysing RWH systems

Model	Developer	RWH only?	Functionality
DRHM	Dixon *et al.* (1999)	No	Mass balance with stochastic elements for demand profiling, simulates quantity, quality and costs
ERWIN (KOSIM)	Herrmann and Schmida (1999)	No	Hydrological-based high resolution (5 minute) rainfall-runoff model
Rewaput	Vaes and Berlamont (2001)	Yes	Reservoir model, rainfall intensity-duration-frequency relationships and triangular distribution
PURRS	Coombes and Kuczera (2001)	No	Probabilistic behavioural, continuous simulation, evaluates sources control strategies
RCSM	Fewkes (2004)	Yes	Behavioural, continuous simulation, detailed analysis of time interval variation and yield-before/after-spill
MUSIC	CRCCH (2005)	No	Continuous simulation, modelling water quality & quantity in catchments (0.01 to 100km^2)
Aquacycle	Mitchell (2005)	No	Continuous water balance simulation using a yield –before-spill algorithm
RSR	Kim and Han (2006)	Yes	RWH tank sizing for stormwater retention to reduce flooding, using Seoul as a case study
UWOT	Liu *et al.* (2006)	No	Object-based behavioural, continuous simulation using Simulink
RainCycle	Roebuck and Ashley (2007)	Yes	Excel-based mass balance continuous simulation using a yield-after-spill algorithm and whole life costing approach

PURRS has been utilised to analyse the affect of RWH on stormwater peak discharge levels (Coombes and Kuczera, 2001); the performance of RWH tanks for supplementing domestic water supply (Coombes and Kuczera, 2003); in the calculation of mains water savings in comparison with other commonly used modelling tools (Lucas *et al.,* 2006) and in comparing centralised water distribution systems with RWH in the context of climate change (Coombes and Barry, 2007). It has also featured significantly in work undertaken at the Figtree Place water sensitive development in Newcastle, Australia (Coombes *et al.*, 1999; Coombes *et al.,* 2002).

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) was developed as an aid to decision making, to evaluate system design and planning strategies for stormwater management. The model provides the ability to simulate both the quantity and quality of runoff from catchments at a range of spatial and temporal scales; 0.01-100km^2 at 6 minute intervals up to 24 hours. MUSIC also models the effects of a range of treatment facilities on the quantity and quality of runoff downstream (CRCCH, 2005). However, MUSIC is not a detailed design tool, as it does not contain algorithms for detailing the sizing of structural stormwater quantity/quality structures – it is billed as a 'conceptual design tool'.

As previously identified the location and sizing of a RWH tank are crucial not only for minimising installation costs and maximising water saving efficiency, but are also important for the maintenance of good water quality.

2.3.9 RWH System Water Quality

The World Health Organisation (WHO, 2008) recognises that rainwater generally does not contain many contaminants, except those derived from the atmosphere. Once such water is harvested and stored it is acknowledged that the quality can deteriorate due to a range of variables. Sources of contamination to the catchment can include wind-blown dirt and animal and bird droppings, leading to potential health risks, though these may be minimised with the use of a first flush device (Fewtrell and Kay, 2007; WHO, 2008). Additionally, processes such as flocculation of physical, chemical and microbiological constituents can occur within the RWH tank, where the aggregated layers then float, settle to the bottom of the tank or adhere to tank walls (Coombes *et al.,* 2005). By undertaking good system design and installation practices, such risks can be minimized. However, where systems are poorly designed and managed, they can pose significant health risks. In the context of the UK, this is reinforced within the British Standard

Institute's Code of Practice for the Installation of Rainwater Harvesting Systems (BS 8515:2009; BSI, 2009), which will be discussed later in this chapter.

Förster (1999) emphasised the importance of investigating the variability of pollution in roof runoff. Other researchers have reinforced this by asserting that it is necessary to evaluate the quality of rainwater, even for non-potable applications, to ensure that it will not be a hazard to users' health in relation to its intended use (May and Prado, 2006). Furthermore, perceptions of harvested rainwater quality and the health risk associated with its use have been indicated as an obstacle to implementation (Morrow *et al.,* 2009).

There exists a large body of research on the quality of water used within RWH systems worldwide (Yaziz *et al.,* 1989, Crabtree *et al.,* 1996, Albrechtsen 2002, Sazakli *et al.,* 2007, Jordan *et al.,* 2008). Some of these studies have been reviewed elsewhere (Lye 2002, Meera and Ahammed 2006, Fewtrell and Kay 2007a). An excellent review of studies between 1989 and 2002 was published by the Australian Cooperative Research Centre for Water Quality and Treatment (CRC, 2005), which is summarised in Table 2.10 along with Australian Drinking Water Guideline (ADWG) indicators. More contemporary studies identified by the author are summarised in Table 2.11.

With respect to developed countries, it can be seen from Table 2.11 that the majority of contemporary studies have originated from Australia, where RWH is accepted as a potable and non-potable supply source (Coombes *et al.,* 2006). In contrast, there is very little UK-based research; both Birks *et al*. (2004) and Fewtrell and Kay (2007a) highlight that data and publications relating to the quality of rainwater supplies in the UK is limited. They affirm that small-scale monitoring studies would provide additional data useful for a health impact approach and standards development.

Furthermore, of the UK studies reviewed by Fewtrell and Kay (2007a), one was conducted with harvested rainwater samples potentially mixed with mains-water and one used runoff samples from farm roofs, before any form of storage. A further study by Wheatley and Surendran (2008) utilised mixed harvested rainwater and greywater samples. Until recent work by Fewtrell and Kay (2009) emerged, the only published UK-based study that had examined *un-mixed harvested rainwater* was Birks *et al.* (2004). However, both of these studies only investigated *microbiological* determinands.

Table 2.10 Summary of previous rainwater quality studies (CRC, 2005)

Parameter	ADWG health	ADWG aesthetic	Albrectsen (2002)	Bannister (1997)	Broadhead (1988)	Coombes (2000)	Crabtree (1996)	Lye (1987)	Olem (1989)	Savill (2001)	Simmons (2001)	Thomas (1993)	Thurman (1995)	Tuffley (1980)	Uba (2000)	Yaziz (1989)
Microbiological																
direct counts			+													
fungi			+												+	
yeast			+													
E. coli	+		+	+						+						
Faecal coliforms	+					+	+	+			+	+	+		+	+
Total coliforms				+		+	+	+		+	+				+	
HPC 20-25C			+			?		+			?		+			?
HPC 35-37C			+	+		?	+	+			?				+	?
Enterococci											+				+	
Pseudomonas	*		+			+									+	
Salmonella	+										+		+		+	
Shigella	+												+		+	
Campylobacter	+		+	+						+	+					
Aeromonas	*		+													
Legionella	*				+						+					
Mycobacteria	*		+											+		
Cryptosporidium	*		+				+				+					
Giardia	*		+				+				+					
Vibrio	+														+	
Aesthetic and nutrients																
pH		+	+	+		+			+		+	+	+			+
acidity		+							+							
alkalinity		+		+					+				+			
phenol-phthalein alkalinity													+			
conductivity				+					+			+				
hardness		+											+		+	
dissolved solids		+				+			+				+			+
suspended solids						+						+				+
total solids																+
turbidity		+		+			+				+	+			+	+
colour		+		+											+	
taste & odour		+													+	

Table 2.10 (continued)

Parameter	ADWG health	ADWG aesthetic	Albrectsen (2002)	Bannister (1997)	Broadhead (1988)	Coombes (2000)	Crabtree (1996)	Lye (1987)	Olem (1989)	Savill (2001)	Simmons (2001)	Thomas (1993)	Thurman (1995)	Tuffley (1980)	Uba (2000)	Yaziz (1989)
non-volatile organic carbon			+													
total organic carbon				+												
dissolved oxygen		+		+												
total nitrogen				+												
total phosphorus				+												
Chemicals																
aluminium	*	+													+	
ammonia	*	+				+									+	
arsenic	+										+				+	
benzo (α) pyrene	+			+												
cadmium	+			+		+			+							
calcium						+			+						+	
chromium	+			+												
chloride	**	+				+			+				+		+	
copper	+	+		+					+		+					
iron	*	+		+		+							+		+	
lead	+			+		+			+		+	+			+	+
magnesium									+						+	
manganese	+	+		+											+	
mercury	+														+	
nickel	+			+												
nitrate	+					+			+			+	+		+	
nitrite	+					+									+	
pesticides	+			+												
potassium									+						+	
phosphate									+						+	
sodium	**	+				+			+						+	
sulphate	+	+				+			+						+	
sulphite													+			
zinc	*	+		+					+		+	+			+	+
vanadium															+	

.
ADWG columns: + signifies a health or aesthetic guideline value exists, * signifies insufficient evidence to set a health guideline value, ** no health Guideline considered necessary. Other columns: + signifies parameter was tested in the relevant study, ? for HPC signifies that incubation temperature was not stated.

Table 2.11 Summary of recent harvested rainwater quality studies

Location	Parameter	Details	Reference
Netherlands	Microbial	Presence of a range of faecal indictor bacteria; identified antecedent rainfall effect	Schets *et al.* (2010)
Papua New Guinea	Microbial, metals	Presence of Enterococci and *Escherichia coli*, high iron/silver	Horak *et al.* (2010)
Australia	Various	Presence of plant derived compounds, PAH* and various metals	Morrow *et al.* (2009)
Korea	Microbial	*E.coli* observed in first flush, little stratification of total or faecal coliforms in the storage tank	Amin and Han (2009)
Australia	Microbial	Presence of potential pathogens did not correlate to faecal indicators	Ahmed *et al.* (2008)
UK	Microbial	Quantification of health risk from *Campylobacter* spp	Fewtrell and Kay (2007b)
Australia	TSS*	Identified sediment re-suspension occurs on outflow events	Magyar *et al.* (2007)
Australia	Microbial, lead	Presence of a range of bacteria, low faecal coliform counts, high lead; examined first flush effect	Martin *et al.* (2007a)
Greece	Various	Low microbial concentrations, acceptable chemical quality	Sazakli *et al.* (2007)
China	Various	Most parameters in excess of drinking water standard	Lushen *et al.* (2007)
Australia	Various	Presence of a range of faecal indicators/pathogens; use in hot water systems >52°C eliminated bacteria	Coombes *et al* (2006)
Australia	Various	Identified impact of antecedent weather conditions on bacterial load	Evans *et al.* (2006a)
Australia	Chemical	Soft water resulted in increased metal concentrations	Chapman *et al.* (2006)
Brazil	Various	Presence of faecal indicators, identified antecedent effects	May and Prado (2006)

*PAH = Polycyclic aromatic hydrocarbons; TSS = Total Suspended Solids

2.3.9.1 Microbiological Parameters

Microbiological contamination often receives the most attention in research, as certain bacterial and viral species have direct implications for human health. However, the level of risk corresponds to the eventual use of the water, which must be put into perspective when assessing the use of a RWH system (Sakellari *et al.*, 2005). Consideration and quantification of the level of risk has recently been furthered by the application of a Health Impact Assessment (HIA) approach to SWM (Fewtrell and Kay, 2008). This is discussed in more detail in Chapter 5, where a HIA on results from the harvested rainwater quality study undertaken as part of this research is reported.

Birks *et al.* (2004) conducted a study of a water recycling facility within the Millennium Dome, UK. Greywater, rainwater and onsite groundwater were used to supply water for toilet flushing (up to $500m^3$/day). Only results from examination of the harvested rainwater are detailed here. Avian faecal deposits on the dome roof were found to be responsible for high post-rainfall levels of the indicator organism, *Escherichia coli* (*E. coli*), with 88% of samples showing concentrations >200cfu/100ml. Other pathogens tested for included *Salmonella*, *Campylobacter*, *Cryptosporidium*, *Giardia*, *Legionella pneumophila* and *Shigella*, with only *Giardia* being observed.

Other studies (Table 2.12) have focused on the microbial analysis of roof runoff, but comparison across studies is hampered by differing design, sampling and analytical methodologies (Meera and Ahammed, 2008) and variable site conditions (Schets *et al.,* 2010). Additionally, the presence of bacteria in the RWH tank may not be detrimental. The formation of biofilms, which are aggregations of microorganisms on the tank sides and any solids, can facilitate the removal of heavy metals from harvested rainwater (Coombes *et al.* 2005). Coombes *et al.* (2005) also found biofilms from different tank materials contained a range of bacteria, with *Bacillus pumilus* and *Bacillus cereus* (originating from soils and the general environment) discovered in all tanks. Other bacterial species were found to be common; however, bacteria in the biofilms were not necessarily detected in the stored rainwater. Biofilms can provide microorganisms with shelter from environmental stresses, such as disinfectants and they may also metabolise compounds harmful to humans. Biofilm thickness has been correlated with capacity for removing constituents, but detaching rates of biofilms and the consequences of detachment have not generally been investigated (Spinks *et al.*, 2003).

Table 2.12 Summary of microbiological studies (modified from Meera and Ahammed, 2006)

Country	Reference	Sample Point	Parameters
New Zealand	Simmons *et al.* (2001)	Tap	HPC; TC; FC; ENT; *Salmonella; Aeromonas; Cryptosporidium* etc
Australia	Plazinska (2001)	Tank	HPC; TC; TTC; FS; *Escherichia. coli*
India	Vasudevan *et al.* (2001)	Roof	HPC; TC; FC; FS
Palestine	Ghanayem (2001)	Roof/tank	TC; FC

HPC – heterotrophic plate count; TC – total coliforms; FC – faecal coliforms; TTC – thermotolerant coliforms; FS – faecal streptococci; ENT – enterococci

The previously mentioned first flush device (Section 2.3.9) was examined in an Australian study by Coombes *et al.* (2006), who identified a treatment train consisting of the first flush device, the rainwater tank and the use of the water in hot water systems. Further to this, Martin *et al.* (2007), also in the Australian context, identified that microbial counts were four and a half times greater from first flush runoff than runoff collected mid-way (10 minutes) through an event. They attributed the increase to dislodgement of accumulated matter between rainfall events. In contrast to this Jordan *et al.* (2008), in a study from the USA, observed that although first flush devices reduced turbidity, bacterial counts remained high after the diversion of the first flush runoff portion. Despite this, they advocate the use of first flush devices to reduce contributions of dust, air pollution and animal waste to the RWH storage tank. In contrast to microbiological parameters, less focus has been given to physico-chemical parameters in academic research, particularly in the UK.

2.3.9.2 Physico-chemical Parameters and Heavy Metals

No published research into the physiochemical characteristics of harvested rainwater supplies in the UK could be identified by the author. This may be due to the fact that physical and chemical characteristics do not generally pose a significant *health* risk when using harvested rainwater for non-potable applications. However, elevated concentrations of such parameters can have implications for RWH *system operation*. For example, Förster (1999) identified that tar roofs exhibit higher polycyclic aromatic hydrocarbon (PAH) concentrations, which can influence the effectiveness of pollution reducing devices such as filters (PAHs also have the potential to be carcinogenic, when consumed).

Additionally, Förster found zinc and copper concentrations in runoff from roofs made of these materials exceeded threshold values causing aquatic toxicity and affecting the disposal or utilisation of sewage sludge and soil. Furthermore, Magyar *et al.* (2007) identified that levels of heavy metals within sediments of RWH system storage tanks exceeded Australian and New Zealand's recreational and irrigation guideline levels, as well as Victorian Environmental Protection Agency (EPA) guidelines for the disposal of waste. This could have implications for non-sanitary use of rainwater (such as garden watering) and for the disposal of sediments after routine storage tank cleaning (Magyar *et al.,* 2007). Such studies demonstrate the importance of roof and building material selection during the design and construction phases and potentially the inclusion of such parameters in standards and guidelines.

2.3.9.3 RWH Water Quality Guidelines and Standards

There are no internationally recognised standards for the quality of harvested rainwater for human use, whether for potable or non-potable applications (Birks *et al.,* 2004). The lack of universal agreement can be attributed to the variable nature of roof surface types, locations, rainfall intensities and durations, dry periods and wind effects (Lye, 2002). The WHO (2006) produced guidance on the safe use of wastewater, excreta and greywater (for example in agriculture); however rainwater is not mentioned within this. In 2008 the WHO revised its 2006 Guidelines for Drinking-water Quality to include an addenda on RWH (WHO, 2008). Although this provides a useful overview of the parameters affecting the quality of rainwater, its primary focus is on the health-based risk posed by drinking, not by utilising rainwater for non-potable uses. For example, although it mentions that metals and other physicochemical parameters can be affected by the action of rainwater on catchment and tank materials (such as zinc roofs); it only advocates monitoring for microbiological parameters, pH and turbidity.

The absence of universal guidance on the use of rainwater, has led to a plethora of country and region-specific guidelines, the content of which usually depends on if potable or non-potable uses are more prevalent within a particular country or region. Some countries, such as Australia and the USA have not set country-level criteria or guideline values (CRC, 2005; TWDB, 2005). However, within these countries some territories and states have devised state-level guidance values for some parameters.

The US state of Texas has made separate recommendations on the minimum quality of rainwater for non-potable and potable uses (TWDB, 2005). For residential and commercial non-potable applications, it is recommended that samples are taken annually and tested for total and faecal coliforms (guideline levels of <500 cfu/100 ml and <100 cfu/100ml, respectively). For residential potable applications other microbiological indicator organisms are included (zero guideline value), along with turbidity (guideline level set as the same for drinking water, 1 NTU). For community and public potable use, harvested rainwater must meet drinking water regulations.

In Germany the Deutsches Institut für Normung or 'DIN' issued the DIN 1989-1:2001-10 standard on the planning, installation, operation and maintenance of RWH systems (part 1), (DIN, 1989). The standard covers noise, fire, frost, catchments, treatment, filters, pumps, control units, pipes, ventilation, overflows, meters, seepage, backflow and tanks throughout the implementation process. Particular mention is given to the prevention of cross-connection, with the notice illustrated in Figure 2.19 recommended for installation on a building's drinking water inlet. However, there are no guideline values for any microbiological or physicochemical parameters within the standard.

Attention! **A rainwater harvesting system is installed in this building.** **Cross-connections are not permitted.**

Figure 2.19 A sign for assisting in the prevention of cross-connections (DIN, 1989)

Since 2000 the installation of RWH systems has been approved in Denmark, subject to compliance with the guidelines produced by the Ministry for Housing and the Environment. Guidelines include that systems can be used for toilet flushing and washing machines, but must be installed by a state-authorized firm with standard-compliant components (Konig, 2001). In Austria there are no specific regulations or codes pertaining to RWH, although the German DIN standards are used widely (Konig, 2001). In France, where RWH is currently not common, a standard for RWH systems is being developed and a consultation is due to be launched in April 2010 (Gerolin, 2010).

In the UK, mandatory values had not been introduced at the time of writing. The most recent guideline values to be issued formed part of the British Standard Institute's standard (BS 8515:2009), based on research conducted between 2001 and 2009 (BSI, 2009). Other regulations and guidance of direct relevance to the installation of RWH systems include:

- The Health and Safety at Work Act (1974);
- The Water Industry Act (1999);
- The Water Supply (Water Fittings) Regulations (1999);
- The Water Regulations Advisory Service (WRAS) Guidance on Reclaimed Water Systems and Marking and Identification of Pipework (1999);
- Legionnaires' Disease. Approved Code of Practice and Guidance (2000);
- The Building Regulations (Parts G and H, as revised in 2009).

(adapted from Shaffer *et al.*, 2004)

Other indirect policies also apply, such as the Confined Spaces Regulations (1997) and the reader is advised to consult Shaffer *et al.* (2004) for full details, though more up to date versions may now be available.

The water quality parameters considered within the British Standard and their guideline values are illustrated in Table 2.13. As can be seen, these are primarily microbiological and thus have most relevance to health-based risk assessment. A limited range of physico-chemical parameters are included. Therefore it could be argued that the assessment of the impact of harvested rainwater quality on the operation of RWH systems and the quality of sediments has not been adequately addressed within the standard. For example, no consideration is given to the concentrations of metals, which can be indicative of the corrosion of fittings by soft rainwater (Ward *et al.*, 2010a) and as previously mentioned can have implications for tank sediment disposal.

Concern regarding harvested rainwater quality and contact with users (or accidental ingestion), for example by aerosols from WC flushing, as well as user perceptions of water quality, is regarded as one of a number of barriers to RWH in many countries, including in the UK (Fewtrell and Kay, 2008). However, in order to maintain good harvested rainwater quality, numerous measures can be undertaken to minimise physical, chemical and microbiological contamination.

Table 2.14 gives an overview of these measures but is by no means comprehensive. A number of these measures reinforce that RWH is not a ‘fit and forget’ technology and that systems require a certain level of maintenance. The previously mentioned British Standard makes recommendations for maintenance activities and frequencies where no supplier information is provided (Table 2.15), which are similar to the DIN standard.

The standard promotes awareness of maintenance activities at the design and installation phases of implementation and an additional document (C626) produced by Shaffer *et al.* (2004) provides a maintenance agreement template for all relevant parties. Additionally, most maintenance activities are simple and potentially feasible for building owners (or maintenance staff) to conduct. However, little is known regarding UK system owner or user attitudes towards commitment to such activities, which is vital for the consistent operation of RWH (and greywater) systems (Shaffer *et al.*, 2004). Such knowledge gaps are part of a range of barriers that impede the more widespread uptake of RWH in the UK.

Table 2.13 Parameters for RWH monitoring within the British Standard (BSI, 2009)

Parameter	Use		System Type
	Pressure washers or sprinklers	**Garden watering/WC**	
Escherichia coli (no/100ml)	1	250	Single/communal
Intestinal enterococci (no/100ml)	1	100	Single/communal
Legionella (no/l)	100	-	As indicated by risk assessment
Total Coliforms (no/100ml)	10	1000	Single/communal
Dissolved Oxygen (mg/l)	>1 (>10% saturation)		All
Suspended Solids	Visually clear and free from floating debris		All
Colour	Not objectionable for all uses		All
Turbidity (NTU)	<10 (<1 if UV used)		All
pH	5-9		Single/communal
Residual Chlorine (mg/l)	<2 (<0.5 for gardens)		All
Residual Bromine (mg/l)	<2		All

Table 2.14 Preventative measures to optimize water quality (compiled from Forster, 1999; Konig, 2001)

Problem	Preventative Measure
Algal growth	Eliminate daylight (use underground tanks)
Stagnation	Avoid use of expansion vessels; keep pipes to infrequent demand devices as short as possible (and use a first-flush device)
Contaminants	Avoid excessively contaminated collection surfaces; install filters; clean collection surface regularly; use appropriate materials for surface construction; orientate new buildings effectively (facing away from pollutant emitters)
Heavy metals	Prohibit use of metal roofs/fittings where RWH is to be used, or install an appropriate coating
Disturbing sediments	Use a calming inlet and a suction float for abstraction
Stratification	Inactive hydraulic flow should not be directed at the tank bottom

Table 2.15 Recommended frequency of maintenance activities in BS 8515:2009 (modified from BSI, 2009)

Component	Activity	Frequency
Gutters/downpipes	Check for leaks and blockages, clean	Annually
Filter	Check condition and clean	Annually
Tank	Check for leaks and debris build up	Annually
	Drain down and clean	Every 10 years
Pump/pump control	Check for leaks and corrosion, test	Annually
Mains top-up	Check for leaks/correct functioning	Annually
Control unit	Check for correct functioning	Annually
Float switches	Check configuration	Annually
Wiring	Check for electrical safety	
Pipework	Check for leaks/correct functioning	Annually
Marking/labelling	Check for correctness/presence	Annually
Support and fixings	Check and adjust where applicable	Annually
UV lamps	Clean and replace if necessary	Every 6 months

2.3.10 Barriers to RWH Implementation

Globally a number of barriers to the implementation of RWH (and indeed SWM) have been identified by a range of researchers. These operate at a range of levels and are summarised in Table 2.16. Further anecdotal evidence suggests that user complaints arise due to poor or incomplete installation, which is undermining trust in the sector before it becomes fully established (Norton, 2010).

Leggett *et al.* (2001) assert that such barriers are not insurmountable but require a focus of attention in order to fully promote the benefits associated with RWH and overcome concerns. The impact of the attitudes of homeowners and new buyers must also not be underestimated; Leggett *et al.* (2001) suggest that differing groups of homeowners have differing perceptions of RWH, some seeing it as a good addition, but it deters others from a property purchase. In 2008, the General Electric Water and Process Technologies report 'Addressing Water Scarcity Through Recycling and Reuse', outlined that successful RWH implementation policies being used around the world fell into four categories: education, barrier removal, incentives and mandates. The report suggested a range of tools including public outreach programmes or award and subsidy schemes (Baker and McKenzie LLP, 2008). In the German context, Partsch (2009) suggests that 'smart' regulation, which combines a three-tiered policy instrument approach, could be beneficial as the three instruments (incentives and water and effluent charging) complement each others' deficits.

Table 2.16 Summary of barriers to RWH implementation (compiled from Leggett *et al.,* 2001; Konig, 2001; Moddemeyer *et al.,* 2003; Hassell, 2005; Brown, 2008; Baker and McKenzie LLP, 2008; De Graaf, 2009)

Institutional	Economic	Technological	Educational
Insensitive Government attitudes	Cheap mains water	Shortage of suitably qualified specialists	Emotional resistance
Water lobbies with special interests	Perceived abundance of water	Reduced summer efficiency due to climate change	Health and safety fears
Political structures with diverging interests	Long pay-back periods	Difficulties with operation/maintenance	Lack of straightforward guidance
Lack of interest from water providers	Initial capital outlay, especially as retrofit	Seen as an unproven technology	Unfamiliarity with technology
Lack of willingness toward innovation	Unproven cost-benefit	Lack of clearly defined water quality and other standards	Seen as an unconventional approach

Focusing on the UK, Roaf (2006) highlights a number of barriers to utilisation of water conservation and reuse. These include lack of empirical data on which to base standards, lack of knowledge at the LA and building design levels, low motives for WSPs to promote SWM, dominance of energy efficiency in Government and public bodies, uncertainty around expected levels of service, aversion to experimental technologies and water quality issues. Additionally, RWH suffers from significant capital cost implications, externalities such as local rainfall/building demand and inclusion constraints (eligibility for financial assistance) in comparison with other energy saving and water efficiency measures (Ward *et al.,* 2009). Furthermore, Bulkeley (2006) highlights that, in a spatial planning context, national policy guidance in relation to water supply is fragmented. She asserts that '*while issues of energy supply and conservation have to date been weakly developed within planning policy, those surrounding water are notable by their absence in most cases*', though as Section 2.2 identified, this is beginning to change.

In 2007 the UK Market Transformation Programme ('MTP'; Brown, 2007) conducted a review of the status of RWH in the UK and recommended addressing the following areas:

- Public awareness;
- Uncertainty over sewerage charges;
- Financial support;
- Regulatory drivers;
- Installer competency;
- Inspection of installations;
- Water quality standards;
- Long term management and maintenance.

These areas are gradually being addressed with the release of regulatory drivers (via the policy documents such as the CfSH outlined in Section 2.2) and water quality standards (via BS 8515:2009). The Chartered Institute for Plumbing and Heating Engineering (CIPHE) is also currently developing an installer competency register called 'Green Plumb' due to be launched sometime in 2010 (CIPHE, 2010). Additionally, some WSPs have introduced new charging structures for surface water drainage, which take into account if a property has a RWH system or SUDS (Severn Trent, 2009; South West Water, 2009; United Utilities, 2009). Publicity of these revised charging structures is currently limited however.

Additionally, although a rating against the CfSH became mandatory for all new dwellings in May 2008, developments only need to meet the minimum standard. For example, social housing funded through the Housing Corporation only has to be built to Code level 3, which (for water) has a performance standard of 105 litres per person per day, representing current best practice in water efficiency *without* requiring water reuse or rainwater harvesting (DEFRA, 2008c). Furthermore, changes to Parts G and H of the Building Regulations only applies to *dwellings*. The onus is put onto the building profession to consider its use in other building types by using methods such as the previously mentioned BREEAM (2007). However, no recommendations are made within these documents regarding where RWH is most suitable; the reader is merely directed to references given, including the recent British Standard (BSI 2009).

These schemes reiterate the encouragement or promotion rather than enabling philosophy with respect to RWH implementation. Although these are positive steps, they fall somewhat short of the ambition of the Progress Report on Sustainable Products and Materials' vision for building and construction that '*Water re-use systems such as rainwater-harvesting and grey water systems—to provide water for toilet flushing and outside use—are standard*' (DEFRA, 2008e). This contradiction is apparently justified in Future Water with the statement that '*As greywater recycling systems—and some rainwater harvesting systems—require energy for treatment and pumping we do not think it appropriate to mandate these types of systems within all buildings*'. This highlights the gap between rhetoric and action as well as a problem common in relation to water management in the policy making and planning sectors; that policy makers and implementers do not wish to be seen as 'favouring' certain technologies over others (Bulkeley 2006).

Robinson (2006) highlights that realisation of an improvement of the energy efficiency of buildings depends on financial incentives, information, building code standards and appropriately positioned public policy, along with intergovernmental harmony and a more actively engaged polity and civil society. There are strong parallels to be drawn here with an increase in the water efficiency of buildings. Although the latter two points are somewhat harder to achieve, steps have been taken towards providing these services for energy. There have been an array of Government funded mechanisms (via the Carbon Trust and the Energy Saving Trust) and financial incentives (such as the now finished Low Carbon Buildings Programme), which apply to all stakeholders (Ward *et al.,* 2009).

In relation to water efficiency, limited support mechanisms are provided by Envirowise; a *business* support-orientated body not dedicated purely to promoting water efficiency and more recently the Energy Saving Trust's remit has been extended to include water. Envirowise recently released a leaflet (Envirowise, 2008) promoting RWH to SMEs. In addition, the Enhanced Capital Allowance (ECA) scheme for the Water Technology List (a tax rebate scheme for water efficient products) again only applies to businesses (DEFRA and HMRC, 2007). Anecdotal evidence suggests that even this is not enough to support businesses in what they would like to do (Hodgson 2008). Furthermore the Government seems immovable in its stance of providing no further financial incentives for RWH, for example to homeowners or other stakeholders: '*There are however no plans for an additional dedicated fund to give grants for this technology*' (DEFRA 2008f).

It would therefore seem that an encouragement rather than enabling approach is currently being undertaken in the UK, despite the previously identified drivers for RWH (Section 2.5.1). The limitations of the policy vehicles outlined place responsibility for the understanding and initiation of the implementation process, as well as a significant financial burden, on 'people' (householders, businesses, developers). This is in direct contrast to a number of other countries who have enabled citizens to install RWH systems, using a wide range of initiatives.

2.3.11 Contrasting the UK RWH Situation to Other Countries

As previously established, Japan, Germany and Australia are currently leaders in the production, implementation and study of RWH systems. Due to the relative success of RWH in these countries this sub-section undertakes a review of the RWH sector features in these countries and compares them to the current status of RWH in the UK.

2.3.11.1 Japan

In 1999 and 2003 underground facilities in Fukuoka City suffered severe damage due to rainfall induced flooding (Yashima, 2009). Another high intensity rainfall event (100 mm/hr) in 2005 in Western Tokyo flooded more than 5000 households, the subway system and major roads (Sugai, 2009). This was followed by a further two major events in 2008, one in Kobe and one in Tokyo (Sakakibara, 2009). In contrast, the per capita availability of water resources in Japan is a fifth of the world average due to a large proportion being lost during flooding events (De Graaf, 2009).

In 1995 the Experimental Sewer System programme and the Association for Rainwater Storage and Infiltration published the Engineering Guideline for Rainwater Infiltration Facilities (EGRIF) in 1995, which were recently strengthened (De Graaf, 2009). Subsequently, in 2004 the Designated Urban River Inundation Prevention Act (DURIPA) was established (Sakakibara, 2009). Consequently, some municipalities in Japan have taken a combined approach to stormwater retention and reuse and have developed stormwater management plans that utilise both storm sewers and stormwater storage tanks receiving runoff from buildings (Takeda *et al.,* 2009; Yashima, 2009).

For example, as part of Fukuoka's 'Rainbow Plan' public facilities have been fitted with runoff control facilities (Yashima, 2009) and Tokyo's Basic Policy for Intense Rainfall aims to create a flood resilient urban environment through individual, mutual and public action (Sugai, 2009). RWH in some areas of Japan has been undertaken due to the passion and dedication of local advocators of the practice and campaigns for public awareness, such as the Rainwater Museum and the Rain Encyclopedia, have been introduced (Murase, 2009). It is recognised that certain representatives undertake important roles in the promotion process (Yoshioka *et al.,* 2009). However, several barriers have been identified to household adoption including cost and the size of tanks, due to land space available in some cities (Yoshioka *et al.,* 2009). This has initiated innovation, such as described in Section 2.3.6 (use of the 'plastic bag' RWH system).

Despite these barriers, Sumida City is a demonstration city for RWH with over 750 community based RWH systems ('Rojison') in place (Figure 2.20). Other buildings, such as the municipal offices and landmark sumo wrestling arena also have RWH, as will the new Tokyo 'Sky Tree' (Figure 2.21). The latter will be completed in 2012 and will collect rainwater from its observation platform roof and associated buildings (including the new Rainwater Museum), with a storage capacity of 2635 m^3. The harvested rainwater will be used for WC flushing, watering green roofs and emergency use (Murase, 2009). There are approximately 2,800 large scale RWH systems nationwide (De Graaf, 2009), although studies into the quantification of the water resource and flooding alleviation benefits from these systems could not be identified.

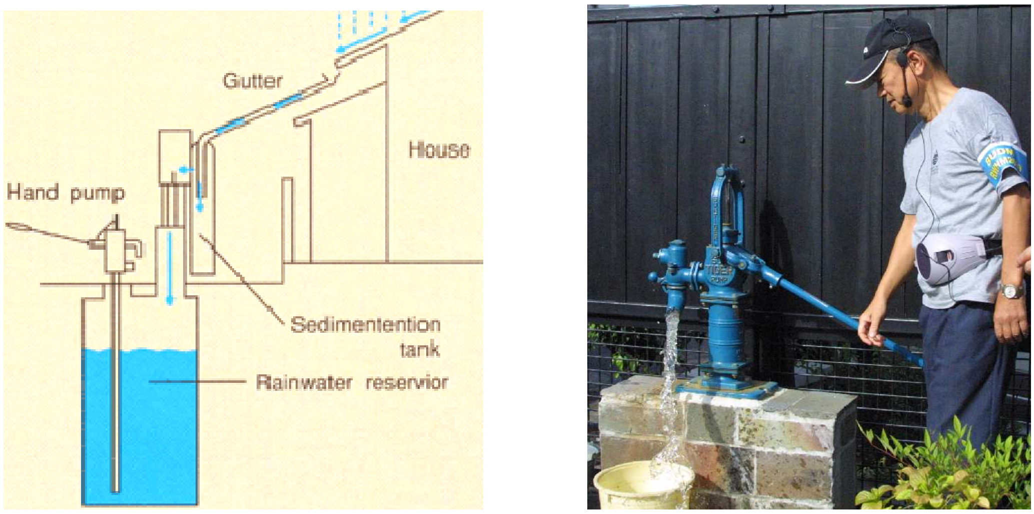


Figure 2.20 Schematic and demonstration of a Japanese Rojison community RWH system (UNEP, 2009; the author, 2009)

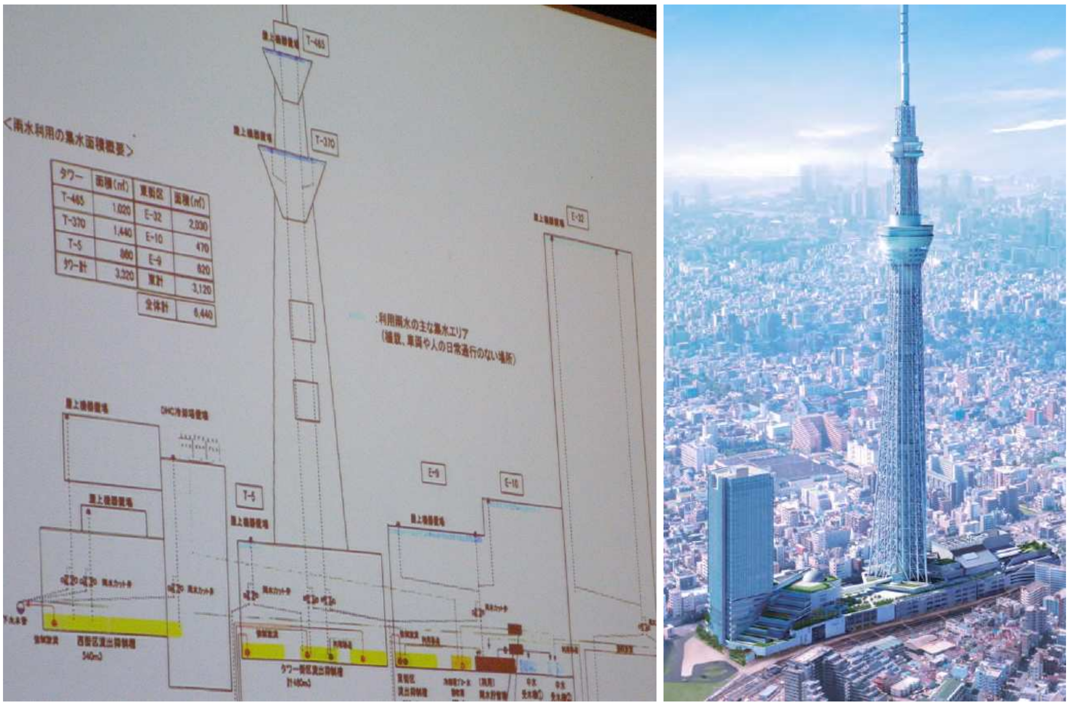


Figure 2.21 Schematic and artistic impression of the Tokyo Sky Tree (public displays photographed by the author, 2009)

The success of RWH in Japan is partially attributed to the creation of a network of municipalities, architects, manufacturers, plumbers and citizens, termed the 'Rain Network Japan' (Murase, 2009). Corporate and income tax benefits, low interest loans and subsidies also exist for alternative water resource projects (De Graaf, 2009).

2.3.11.2 Germany

RWH in Germany has been utilised since the beginning of the 1980s, as an alternative to combined and separate sewers to protect water bodies from polluted stormwater. This is in response to a number of drivers, including compliance with the Urban Waste Water Treatment Directive (UWWTD) by reducing combined sewer overflow (CSO) releases (Butler and Ward, 2009). Consequently, new developments are required by law to retain and infiltrate rainwater (Nolde, 2007). It is estimated that between 50,000 (Nolde, 2007) and 80,000 (Partzsch, 2009) domestic systems are installed each year, but again information on their effectivity as alternative water supply and flooding alleviation measures was limited.

Germany has an established standard (DIN 1989-1:2001-10), a contracting model (summarised in Figure 2.22) and a building code (equivalent to the UK CfSH) entitled the German Sustainable Building Certificate (GSBC), which is administered by the German Sustainable Building Council (DGNB, 2009). Additionally, subsidies are available for RWH systems in some areas (Kellagher and Maneiro Franco, 2005).

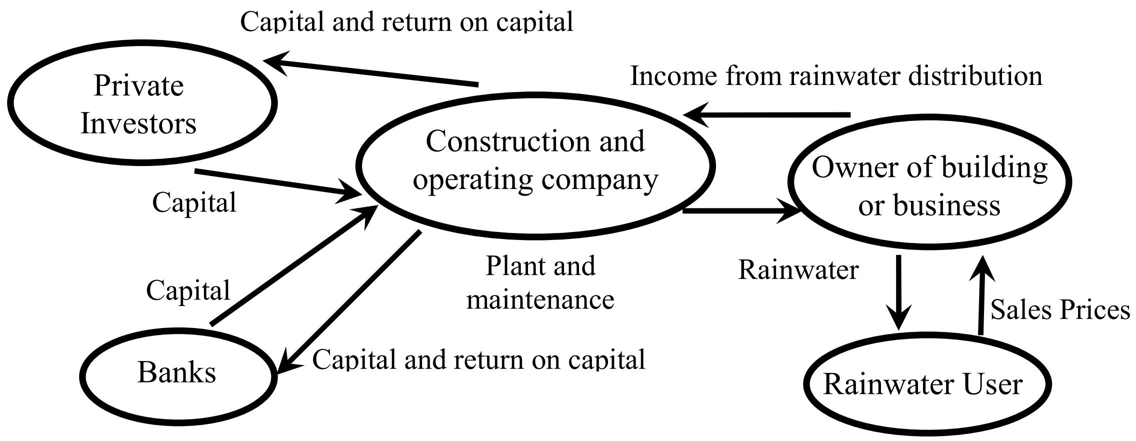


Figure 2.22 The RWH contracting model in Germany (Konig, 2001)

In the Land of Hamburg a grant of up to 50% of the cost is available and in the Land of Bremen subsidies are available for up to a third of the cost (up to €2000). In Berlin, Berliner Wasserbetriebe (the local utility) has implemented a programme of measures including monetary incentives for green roofs and SUDS on private properties and promotion of the unsealing of impervious surfaces and implementation of decentralised SUDS (Butler and Ward, 2009). In addition, increased demand and high water extraction, supply and effluent fees mean that alternatives to the WDS are frequently sought (despite the obligation to connect to the WDS) and it is estimated there are currently 1.5 million systems nationwide (Partzsch, 2009).

These support systems have been driven by the German government, which has the desire to improve the market opportunities of companies by assisting green technologies via appropriately directed innovation policy. Despite this, the German retrofit market is not well developed as the law for new developments does not apply to existing buildings (Partzsch, 2009).

However, the Emscher region (in the North Rhine-Westphalia area) is undertaking a large scale RWH and infiltration project along the ‘Rainwater Route’ (Figure 2.23 and Figure 2.24), for which €4.5 million was provided for the implementation of RWH (Becker and Raasch, 2001).

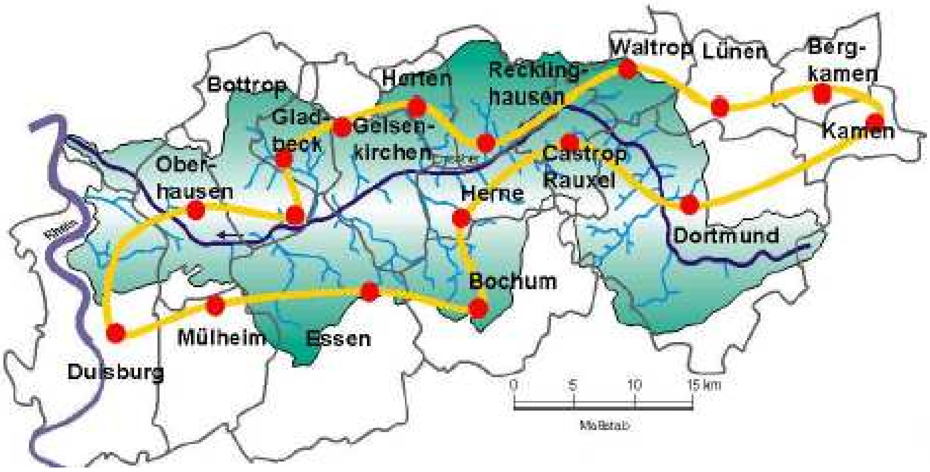


Figure 2.23 Emscher’s 'Rainwater Route' (Becker and Raasch, 2001)

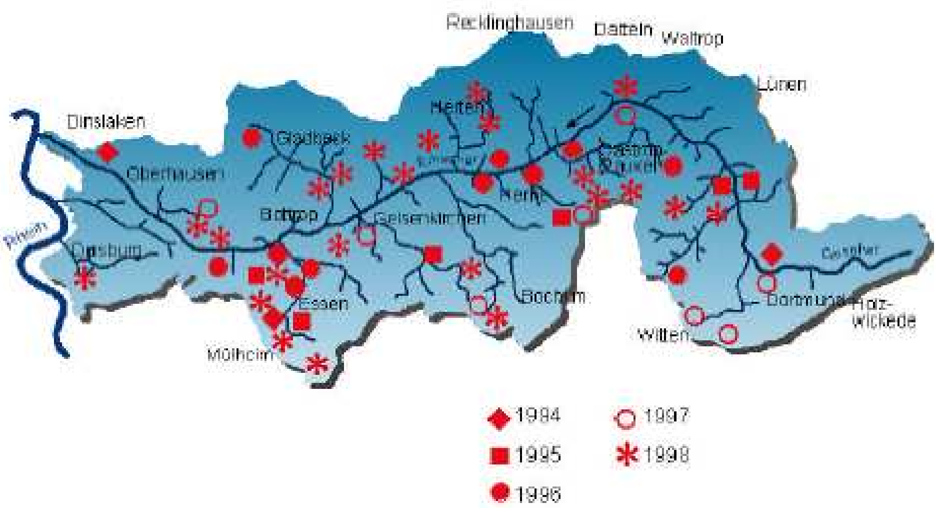


Figure 2.24 Rainwater and infiltration projects in Emscher (Becker and Raasch, 2001)

The subsidies amounted to €5/m² of impervious area disconnected from the drainage system. Since 1994, 18 towns have participated with a total of 82 different projects and 47 projects have been or are being implemented. These pilot disconnection programmes are centralised into a Geographical Information System (GIS) known as the Stormwater Management Information System, 'SMIS', based on the Open Geospatial Consortium (OGC) standard. SMIS allows local authorities to easily identify feasible disconnection measures to implement in other areas, as well as calculating the percentage of an area with potential for disconnection (Geretshauser and Wessels, 2007). With this level of disconnection, the flood peak flow in the tributaries of the Emscher could be reduced by as much as 40 %, in the case of minor floods with a two-year return period – though no empirical evidence of this benefit was identified. The resulting significant reduction in the flow-erosion of the bed of the watercourse is of immense ecological importance for the tributaries of the Emscher (Becker and Raasch, 2001).

2.3.11.3 Australia

The driest inhabited continent on Earth, Australia, receives an annual average rainfall of 469 mm/yr (White, 2009). For the eastern and southern coasts it is forecast that the impact on the area's water resource will result in the centralised WDS not being recharged at the rate it is consumed, due to an extra ground saturation requirement (White, 2009). This is already apparent in some areas, where a long-term drought has had a widespread impact on water resource management (Marsden Jacob, 2007).

In 1995 a coalition of state governments revised water management policy to incorporate SWM processes, after which new reforms and acts were implemented at the state level (White, 2009). In 2004 the National Water Commission established the National Water Initiative in conjunction with the Council of Australia Governments (NWC, 2009). One of the aims of the NWI is to encourage innovation in water supply, such as by using RWH and GWR (where appropriate) to ensure the most effective combination of measures for water security (Marsden Jacob, 2007). Consequently, some states have set targets for demand reduction and water reuse increase (Table 2.17). Additionally, a national Water Conservation and Reuse Research Program was initiated (Mitchell, 2004).

Some state governments have made the installation of RWH in new developments compulsory. In New South Wales this has been supported with the introduction of the

Building Sustainability Index (BASIX) regulatory framework and sustainability indexing tool (Naji and Lustig, 2006)), which is similar to the CfSH in the UK. BASIX is a web-based planning tool, consisting of several modules relating to assess the sustainability of residential developments in areas such as energy and water. For the water module (Figure 2.25), a development is assessed for its estimated water consumption and scored accordingly against a 5 star rating. Including RWH or GWR improves the score of the development. However, the scheme has been criticised as not providing a comprehensive approach to total water cycle management that includes social and environmental objectives.

Table 2.17 Summary of state ambitions for water resource management (compiled from Hatton-MacDonald and Dyack, 2004)

State	Strategy	Target
Victoria	Water Recycling Action Plan	20% reuse of wastewater in Melbourne by 2010
New South Wales	Water Conservation Strategy	35% reduction in PCC water consumption
Queensland	Water recycling Strategy	No fixed target; promotion of reuse
Western Australia	State Water Strategy	20% increase in reuse by 2010
South Australia	Water-Proof Adelaide	No fixed target; review of stormwater management
Tasmania	Wastewater Reuse Coordinating Group	No fixed target
Australia Capital Territory (ACT)	Various	20% recycling by 2013
Northern Territory	Follows national policy	No fixed target

In terms of financial support, the NWC enacted the National Rainwater and Greywater Initiative, which purely supports the *retrofitting* of RWH systems with subsidies (DER, 2009). Tenanted properties, however, are not eligible (unless they can persuade the property owner to install a system). The initiative was renewed in 2009 with a fund of AUD $250 million and is open until 2014. The initiative provides rebates of up to AUD $500 for domestic installations and AUD $10,000 for Surf Life Saving Clubs, as well as providing guidance on the type of system to install and how to use it (DEWHA, 2009). Prior to this, by 2006 Brisbane City Council had rebated 21,000 domestic RWH installations (White, 2009). This financial support has resulted in a high percentage of penetration of RWH in each state, used for both potable and non-potable applications (Table 2.18). These figures do not of course include systems at other non-household scales. It is estimated that nationally there are 1.3 million domestic systems throughout

Australia and that 2.1 million other households were considering installation of a system (Standards Australia, 2006).

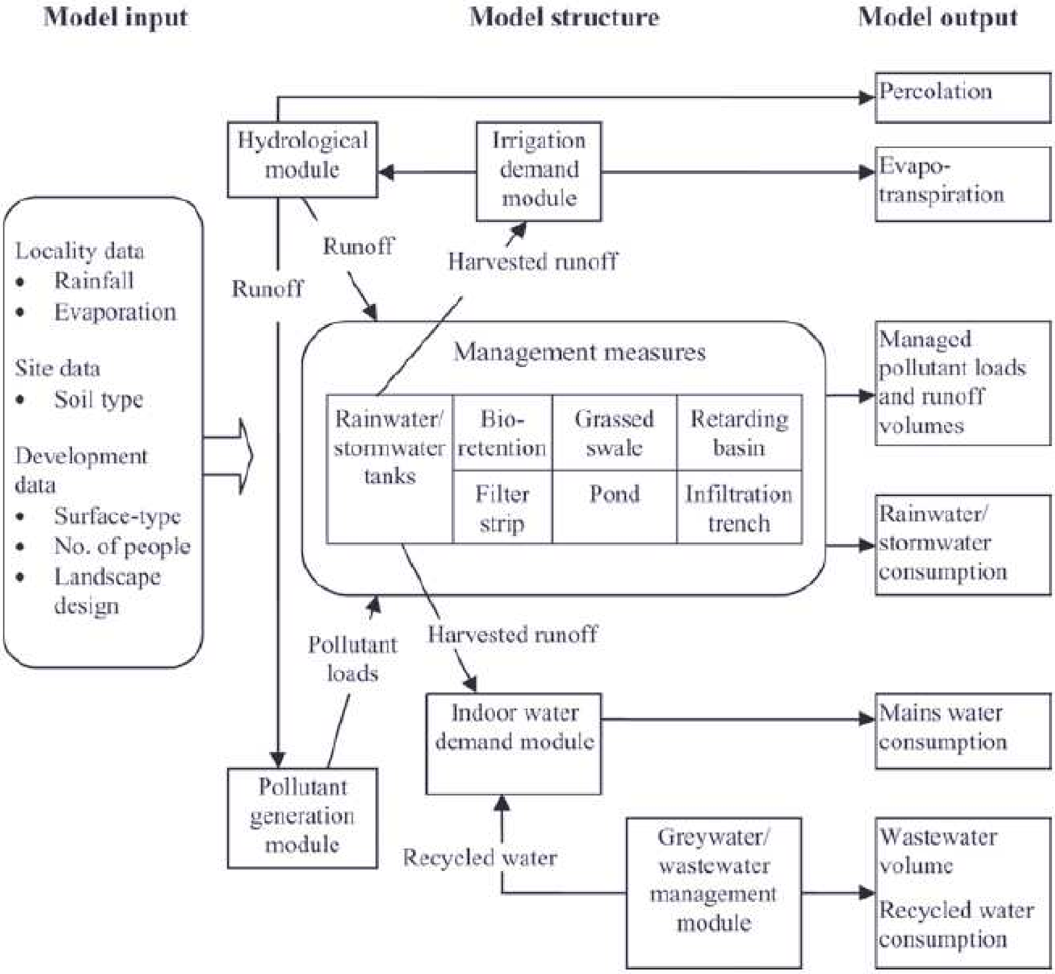


Figure 2.25 Schematic of the BASIX water module (Naji and Lustig, 2006)

Table 2.18 Percentage of RWH penetration in Australian states (Enhealth, 2004)

State	Households with RWH (%)	RWH as main potable source (%)	Capital city households with RWH (%)	Non-capital city households with RWH (%)
New South Wales	10	8	3	30
Victoria	13	11	3	36
Queensland	18	15	5	29
South Australia	51	36	37	80
Western Australia	11	8	5	30
Tasmania	17	14	6	19
Northern Territory	3	2	Nd	Nd
ACT	1	0.2	Nd	Nd

Nd = not determined

To further support the uptake of RWH systems, a standard for installation entitled the National Rainwater Tank Design and Installation Handbook (NRTDIH) was published in 2006 (Standards Australia, 2006; Chapman *et al.*, 2008). The standard was developed by SA, the Master Plumbers' and Mechanical Services Association of Australia (MPMSAA) and the Australian Rainwater Industry Development Group (ARID). Furthermore, public awareness campaigns have been undertaken, such as that by the Smart Water Fund in the state of Victoria (2005), which took the following actions:

- Multimedia presentations;
- School education packs;
- Mass media advertising;
- Radio campaigns;
- Public exhibitions.

Key messages of the campaign were directed towards raising awareness of RWH for a range of uses other than just garden watering, its contribution to mains water consumption reduction and reduction of the impact of peak storm water events on sewers and that installation can be unobtrusive and cost-effective. It is estimated to have reached over 2 million residents by 2005 (Smart Water Fund, 2005).

2.3.11.4 UK Comparison

The preceding literature review of the RWH sector in other countries has identified a number of initiatives that appear to be contributing to the success of the technology. The main features of the implementation programmes in operation uncovered by the literature review are summarised in Table 2.19 in comparison with the UK. Of course this is not a comprehensive assessment, but was limited by the information available for each country. Despite the previously outlined barriers to RWH in the UK, Table 2.19 identifies that the sector has made significant progress at a policy and standards level in line with the models exhibited by other leading RWH countries. However, the areas in which the UK appears to be deficient, in comparison to the leaders, are financial support and public engagement. This echoes the findings of the MTP (Brown, 2007) project and other literature cited in Section 2.3.10.

Examination of the status of RWH in the UK in comparison with other RWH ‘leaders’ has identified that the status of RWH in the UK is beginning to reflect the features of a system in which widespread implementation may be successful. However, barriers still exist including in particular the engagement of stakeholders. The drivers, system types and barriers identified throughout this section highlight that although RWH is a technical SWM measure, its design, implementation and use has a significant interplay with a range of sociological factors. These include unfamiliarity, installer expertise, user perceptions and action, financial ability and institutional guidance. The next main section of this chapter provides a discussion of previous research that has considered RWH from a sociological perspective. This includes examination of a range of social research theories and frameworks, which may be useful for breaking down the remaining barriers, maintaining the current momentum and facilitating a comprehensive socio-technical approach to supporting the continued implementation of RWH in the UK.

Table 2.19 Comparison of the features of the UK RWH sector with other countries

	Japan	Germany	Australia	UK
Driver	Flooding; Water supply	Water demand & cost; UWWTD; Drive green technology market	Drought	Increased water demand; Flooding
National Water Policy	DURIPA	No	National Water Initiative	Future Water; F&WMA
Regional Water Policy	Rainbow Plan; Basic Policy for Intense Rainfall	Rainwater Route	Various	Various via spatial planning system
Building Scheme	Unknown	GSBC	BASIX	CfSH
Design/Installation Standard	EGRIF	DIN 1989-1:2001-10	NRTDIH	BS 8515:2009
Financial Support	Corporate/income tax benefits; low interest loans; subsidies	Subsidies	Subsidies/rebates	Tax allowance for businesses only
Product Innovation	Yes	Yes	Yes	Yes
Public Engagement	Rain Network Japan; Rain Encyclopedia; RW Museum	Unknown	Public awareness campaigns	None at present

2.4 SWM, RWH and Social Research

The previous section identified that a number of barriers remain to the implementation of RWH in the UK and that stakeholder engagement activities are currently low. Identification of individuals as the key agents of environmental change was first outlined in Agenda 21 in 1992 (Konig, 2001). This has led to personalised actions and home-centred behaviours becoming key priorities for LAs in order to achieve government and internationally-set policies and environmental and efficiency targets (Barr and Gilg, 2007). However, such approaches can lead to blinkered consideration of the 'Awareness, Information, Decision, Action' logic of behaviour (also termed the 'information deficit' model), which assumes that making individuals aware of environmental issues will help resolve them (Sefton, 2009).

The UK government has recognised that information alone does not lead to behaviour change and has produced the 'Framework for Pro-environmental Behaviours' (FPEB) (DEFRA, 2008a). However, there remains a certain level of assumption that environmental actions can be compartmentalised into behavioural 'segments', depending on an individual's '*attitudes, barriers, motivations and current behaviours*' (DEFRA, 2008a). Segmentation is undertaken in order to target particular population groups and tailor approaches to specific groups. Macnaghten and Urry (1998) and Sefton (2009) argue that such approaches do not account for an individual's alternative perceptions of trust and responsibility, the differing perspectives of promoters and receivers of information, or the influence of social context. Barr and Gilg (2007) defend the information deficit model, highlighting that although a culturally informed approach provides in-depth and strong data on individual situations, it contributes less to wider perspectives and large-scale policy decisions.

The FPEB does highlight, however, that there are more challenging arenas in which to address behaviour change, such as where there is a low ability and a low willingness to act (for example in installing rainwater harvesting) or where willingness is low although people acknowledge that they could act (for example by not installing power showers). This is reinforced by Sefton (2009) who, in the context of SWM, identifies that if the public are to be engaged with SWM then ways must be discovered by which SWM engages with the social concerns of the public.

An emerging technique with this in mind, already popular in the USA and recently applied in the UK in designing sustainable communities (Duany, 2009), is the Charrette System (NCI, 2009). The process is conducted over at least four consecutive days, to allow three feedback loops, during which meetings, presentations and workshops are held, which include all interested parties. In addition, public consultation has been identified as a key factor for enhancing the receptivity and acceptance of water demand management approaches (Sharp, 2006).

To date, most studies have tended to focus on behaviour change in relation to overall SWM or WDM activities, such as metering or the retrofitting of WSDs (Sharp, 2006). However, WDM can only reduce consumption; it cannot assist in the reduction of localised flooding via source control, which RWH may be able to facilitate (Memon *et al.,* 2009). Therefore an understanding of how people view RWH systems and what is acceptable or realistic for them to consider, are fundamental aspects of promoting and facilitating installation and subsequent proper use of such systems (Sefton, 2009).

2.4.1 RWH and Applied Social Research

Until recently there has been limited research conducted into the attitudes and perceptions of stakeholders in relation to alternative water sources, such as RWH. This deficit is particularly noteworthy in the UK, where only two previous studies could be identified. One was a survey on water efficiency, including RWH, which was administered to house-builders (Goodhew *et al.*, 1999) and the other a very short telephone survey conducted with the general public by a RWH system supplier under the auspices of the 'Save the Rain' campaign (BMRB, 2006).

The most recent UK research (Parsons *et al.,* 2010) to examine the uptake of RWH, duplicated and extended Goodhew *et al.*'s work and focused on the perceived and existing barriers with respect to the perspective of housing developers. The study identified that the barriers preventing uptake are:

- Institutional and regulatory gaps;
- Economic and financial constraints;
- Absent incentives;
- Lack of information and technical knowledge;

- House builder attitudes.

Given the ‘lack of information and technical knowledge’ and ‘house builder attitudes’ it could be hypothesized that house builders may not understand the needs of their potential purchasers and thus the type and extent of system acceptable to them.

Globally, only a few studies have examined in detail, the perceptions and experiences of individuals in relation to RWH, GWR and recycled (reclaimed) water (system users and non-users). Hurlimann (2006) implemented an online survey with office workers about to be relocated to an office building containing a recycled water system in Melbourne, Australia. The system was to be used for supplying the cooling system, toilet flushing, plant and street tree watering and street cleaning. 47% of respondents were ‘happy’ to use recycled water for drinking and 99% were ‘happy’ to use it for watering gardens and street vegetation. The study also found that prior experience of recycled water systems positively influenced acceptance of proposed use within the office building.

Hurlimann (2007a) conducted the same survey, with a few additions, on a second office building in Bendigo, Australia. Similarly to the first study, 42% of respondents were ‘happy’ to use recycled water for drinking and 99% for toilet flushing. In contrast to the first study, however, it was identified that there were significant differences between demographic groups. Males were found to be more accepting than females and respondents over the age of 50 were happier to use recycled water for washing hands, indirect and direct drinking. Additionally, respondents with a university degree were happier to drink recycled water indirectly (added to the drinking water reservoir/river after being treated).

A final study by Hurlimann (2007b) directly assessed perceptions of risk associated with a range of uses of recycled water within an Australian community (Mawson Lakes, Adelaide, Australia). Respondents were asked to rate how risky they thought certain uses were on a scale of 0 to 10, with 0 being ‘not at all risky’ and 10 being ‘extremely risky’. It was found that the perception of risk increased as the use became increasingly personal.

A recent study in relation to the experience of individuals with RWH was identified, which conducted an investigation into the factors influencing the adoption of the technology in households in South East Queensland (SEQ), Australia (White, 2009). In the study, two theoretical perspectives relating to decentralised environmental technology adoption are explored. The first is ecological modernisation (EM), which situates households as consumers in a market acknowledging a move towards the utilisation of sustainable technologies. This approach considers systemic (governance and regulation, economic availability, supply chain modification) influences on the adoption of technologies. However, it does not account for the experience of the individual in the way it addresses social consumption. The UK MTP (Brown, 2007) adopted a primarily EM point of view.

The second perspective is diffusion of innovation (DI), which complements EM by providing an emphasis on the distinctiveness and temporal variability of the consumer experience (White, 2009). The UK FPEB segmentation method goes some way towards achieving a DI approach. In combining the EM and DI perspectives, White (2007) claims that clarification of the issues associated with household motivations to use RWH technologies could facilitate production of better information and the targeted promotion of RWH systems.

The study undertakes a synthesis of factors influencing and catalysing household adoption of RWH from both the EM and DI perspectives. These are defined as:

- Cost and economy
- Environment
- System Sophistication
- Independence
- Community
- Visibility
- Governance and Regulation
- Relative Advantage
- Compatibility
- Voluntariness
- Image
- Ease of Use
- Experience
- Technological Innovation

These were incorporated into a complex questionnaire and administered to residents (both RWH system users and non-users) in five states of SEQ. In total 254 full and 25 partial (between 50% and 90% completed) questionnaires were returned, with cooperation and response rates of 48.4% and 32%, respectively (cooperation and response rates are defined in Chapter 3, Section 3.3.1). An extensive and robust statistical analysis of the results was then undertaken, including the use of Fleiss' Kappa (to assess inter-rater reliability; that being the consistency of analysis across multiple analysts), Cronbach's Alpha (a measure of construct validity; defined in Chapter 4, Section 4.4.6) and Principal Component Analysis (PCA). This was complemented with the use of Discriminant Function Analysis (DFA) and an inverse MANOVA (Multi-variate analysis of variance), to allow prediction of whether a participant was a RWH system user or non-user using their questionnaire score.

The study identified that 78.2% of participant's responses could be attributed to the pre-determined factors. For RWH system users Independence (22%) and Relative Advantage (17%) were the most influential, with Cost and Economy ranked third (13%). For non-users Cost and Economy (35%) was the primary influencing factor. Factors derived using both EM and DI were implicated in the responses, although DI dominated slightly. The top four factors overall were (listed from highest to lowest influence): Cost and Economy, Relative Advantage, Independence and Environment. Furthermore, the statistical model constructed was able to discriminate between participants (users and non-users) based on their questionnaire scores. The full conceptual and statistical model was termed the 'Decentralised Environmental Technology Adoption' or 'DETA' model.

A second study to adopt the EM and DI perspectives in relation to RWH is that by Partzsch (2009), this time in the German context. The perspectives are used to examine the regulatory instruments in place in Germany that facilitate the implementation of RWH. It is asserted that supporting the implementer requires 'smart regulation', that being (for the German market) the interaction of three financial instruments (water abstraction fees, water supply and effluent fees and subsidies), rather than their implementation in isolation. Additionally, it is recognised that actors at various levels ('change agents', 'blocking agents') need to be mobilised to establish the value of smart regulation.

In addition to the EM and DI approaches favoured by White and Partzsch, a number of other social research theories and frameworks have been applied to the fields of SWM, which are potentially of relevance to the implementation of RWH.

2.4.2 RWH and Theoretical Social Research

Previously, Hardin's rational choice model was widely applied to develop an understanding of how to engage stakeholders with various aspects of sustainability Sefton, 2009). The model assumes that individuals make unprincipled, convenient and financially-focused decisions regarding actions towards the environment (Geels and Schot, 2007). However, it is recognised that engaging people in SWM needs to move beyond this approach (Sefton, 2009). Additionally, the level of the individual and the level of the institution need to be interwoven to gain the greatest insight into SWM/RWH implementation (White, 2009).

Brown and Keath (2007) draw on social theory (incorporating evolutionary economics and technology studies) to examine the current position of SWM as an approach to urban water management. They hypothesise that a major socio-technical transition is required to overcome the barriers to uptake. It is proposed that such a transition can be catalysed by understanding the following areas of research:

- Technology Diffusion (similar to Diffusion of Innovation);
- Transition Theory or the 'Multi-level' Perspective;
- Model of Receptivity.

More recently, Sefton (2009) focused on the level of the individual and hypothesized the following social theories were important in determining how stakeholder engagement with SWM could be facilitated:

- Self-efficacy;
- Social identification;
- Social representations.

The main features and potential relevance of these theories to the present research is discussed in the following sub-sections.

2.4.2.1 Technology Diffusion

Diffusion of innovation or technology diffusion offers a multi-stage process model to explain how new and innovative technologies become mainstream (Brown and Keath, 2007). The four phases of the process (A) and the corresponding groups characterised in each phase (B), as well as in the later post-diffusion phases, are illustrated in Figure 2.26. Phase 1 is termed 'Pre-development', as there is only experimental activity, no change to mainstream practice and only a few 'Innovators' (I) exist. In phase 2 the innovation has reached 'Take Off', the innovation is supported through research and development and the number of implementers, the 'Early Adopters' (EAs), rises. Phase 3 represents 'Acceleration', where change occurs at the institutional level and there is a steady and maintained increase in implementer numbers (the 'Early Majority' (EMy)). The final phase of the diffusion, 'Stabilisation' (Phase 4) sees widespread acceptance of the innovation and it transitions into the mainstream with the 'Late Majority' (LM) and 'Laggards' (L) implementing after this phase (Rogers; 1995; Brown and Keath, 2007; White, 2009).

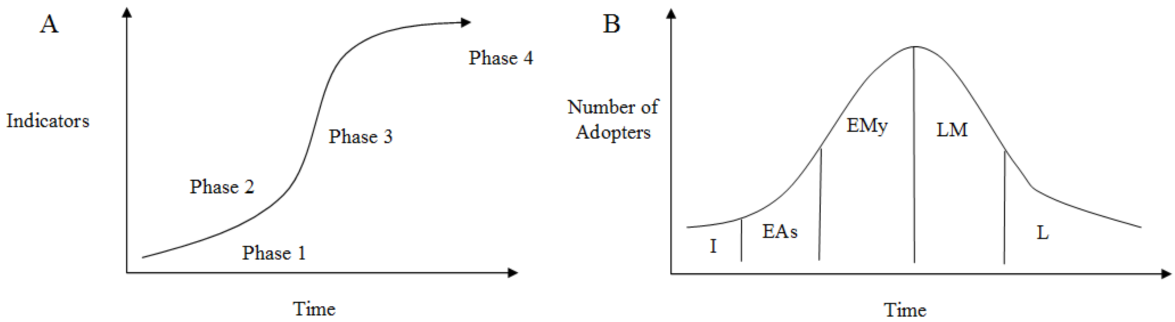


Figure 2.26 The S-curve model of technology diffusion (A) and adopter groups throughout the diffusion process (B), (modified from Brown and Keath, 2007 and White, 2009)

Rogers (1995) goes further to propose attributes for the implementer group types, although these could be disputed:

- I – adventurous, educated, access to information, risk taker;
- EA – leader, educated, popular;
- EMy – deliberate, extensive social contacts;
- LM – skeptical, less educated;
- L – fearful of debt, rely on word of mouth.

In terms of relevance to RWH, the previous section identified that many measures are currently being implemented in the UK, through which the uptake of RWH is speculated to increase. Assessment of the position of RWH in the UK on the diffusion S-curve could identify which groups of implementers need to be engaged – EAs, EMys or both? This could potentially help support the application of DEFRA's segmentation approach to RWH (or SWM).

2.4.2.2 Transition Theory

At the other end of the implementation or transition scale to individuals or organisations lies the regime (the current paradigm or 'status quo' of a sector) and the landscape (the overall situation of the regime in relation to the presiding view held by society), (Geels, 2002). Geels (2002) proposes the multi-level perspective to understand the relationships between these scales in undergoing a technological transition (TT). There are obvious parallels between Geel's analysis of TT and Roger's technology diffusion. For example, the multi-level perspective consists of the macro (landscape), meso (regime) and micro (niche) levels, which correspond approximately to Phase 1 (macro), Phases 2 and 3 (meso) and Phase 4 (micro) of the technology diffusion S-curve. Geels and Schot (2007) demonstrate this through the use of Figure 2.27; the S-curve can be seen as the series of small arrows, the thin, black arrow and then the dashed arrow that moves from the bottom left to the top right of the figure.

The model proposes TT results from the accumulation of niches in response to regime and landscape level changes. These are induced either by crisis or the emergence of growing needs, new markets or new opportunities. It is the micro level that responds to these drivers, in the form of advantageous technologies, representing variation. The niche then requires reciprocal reconfiguration of the upper levels to become accepted. This is often facilitated by the emergence of specialized actors, which help select and retain the appropriate advance. This is the main tenet of the theory – levels interact in all directions (bottom-up, top-down and horizontally) and transitions are dependent on these interactions to link and reinforce the multi-level change. Therefore TT requires changes not only in a technology, but also in '*technology external*' factors - practices, regulation, networks and actors - as well as involving experimentation and learning. Geels (2002) comments that niches may demonstrate relatively low technical performance and may be cumbersome and expensive, as skills and practice adjust to the requirements of new drivers. Selection and retention activities executed by markets lead to the strongest and most appropriate niches becoming accepted.

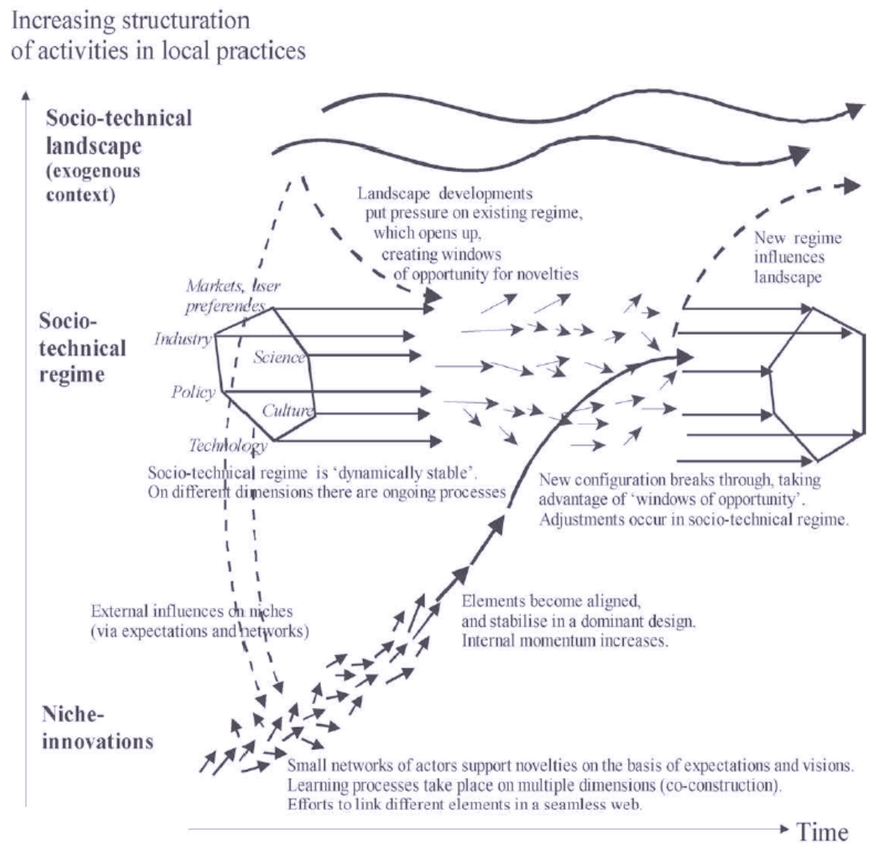


Figure 2.27 The nested hierarchy of a technology transition (Geels and Schot, 2007)

Geels (2002) demonstrates the application of the perspective to the historic transition from sailing ships to steamships in the 18th to 20th centuries and Brown and Keath (2007) apply it to the emergence of SWM in Australia. The latter study highlights that there are currently a range of macro-level pressures (such as drought) in the urban water regime and alternative water sources have been developed at the micro level for sometime. They reinforce the value in nurturing interactions across the multi-level. Geels and Schot (2007) further develop the theory into four types of transition pathway (also illustrated on Figure 2.27), based on the timing and nature of the multi-level interactions:

- Transformation;
- Reconfiguration;
- Substitution;
- De-align/realignment.

The pathway model also asserts that there may be a *sequence* of transition paths, depending on whether the destabilisation of the landscape (or regime) is gradual and specific or rapid and disruptive. The transition to the use of RWH, based on the discussion in Section 2.3.11.4, could be seen as being both gradual and disruptive, as it significantly challenges the normalised concept of potable water for every use. Perhaps the most appropriate of the hypothesised pathways for RWH is *substitution*, as the centralised WDS becomes *substituted* (where appropriate) with decentralised RWH for a range of non-potable uses. Of course, the start of the substitution inevitably begins with *reconfiguration* and *de/realignment*, as actors at all levels adapt to its practice. *Transformation* of the regime or landscape to utilise RWH for every end use is, however, somewhat unlikely, as the dominance of the WDS permeates too many markets and sectors and society's reliance on turning a tap to receive potable water is perhaps too great. Therefore for RWH it appears that the *nature* rather than *timing* of the transition is most important.

The TT process also echoes elements of implementation theory, as described by Pressman and Wildavsky (1984) using a case study on the implementation of a project to stimulate economic development in Oakland, California (USA). The study highlights the difficulties of the implementation process and structures it in terms of policy formulation and its trials (macro level), the complexity of joint action (between levels), learning from experience (at all levels) and implementation as an evolutionary process requiring mutual adaptation and exploration of successes and failures across levels.

Neke *et al*. (2009) demonstrated the value of the multi-level perspective in application to RWH in developing countries, which has resonance for a potential approach for developed countries. In constructing the 'RAIN' capacity building network, they consider stakeholders from the macro, meso and micro levels, including non-governmental organisations (NGOs), governmental organisations, universities, private sector, consultants and system users. The network consists of:

- RWH Capacity Centres (RHCCs) acting as coordinators and supporters;
- An Implementing Organisations Body;
- Advocacy and Information Sharing (training at all levels);
- Improvement of Technologies (including relevance and accessibility).

They highlight that a multiplier capacity building effect is experienced when there are strong linkages between NGOs, education establishments and public and private services, but that governments can limit action by not investing in RWH.

2.4.2.3 Model of Receptivity

The previous theories and frameworks have mainly focused on the overall implementation process and its components, primarily from a top-down point of view. Down-sizing from the transition/multi-level perspective and moving away from the discussion of its parts, finds social theory taking a bottom-up approach focusing on the level of the individual stakeholders involved in the actual implementation and transition process. As highlighted throughout the preceding discussion, these 'elements' are crucial for developing, trialling and adopting new technologies and adapting or adjusting to the changes of niches and regimes.

The model or framework of receptivity, developed by Jeffrey and Seaton (2004), consists of the four attributes of awareness, association, acquisition and application and is based on literature from innovation and technology transfer policy. The framework's basic premise is that policy change instruments designed from the recipient or 'user' (individual, organisation) perspective will be more successful, as the failure of interventions often relates to the ability of users to implement change into their situation. Therefore identifying the recipient's level of receptivity or ability is a crucial starting point to pursuing successful policy adoption and its subsequent marketing (Figure 2.28).

Jeffrey and Seaton (2004) assert that previous research into effective policy implementation has focused on maximising the *application* of the policy rather than in *understanding* stakeholders' receptivity, ability and willingness (i.e. capacity) to adopt it. The study applies the framework to several case studies on SWM, water filters and water recycling. Only the latter is discussed here, due to its relevance to the current research topic, to demonstrate the attributes of the framework. The receptivity framework was utilised to design a social enquiry activity, that being conducting a survey on in-house water recycling with a sample population. It was then used to analyse the results. Findings were potentially useful for improving the water recycling system design in terms of functionality and aesthetics, as well as the financial, regulatory and social concerns. Particularly noteworthy was the role of legitimacy and credibility in acquiring stakeholder trust in relation to water quality. The framework attributes, their relevance in the case study and potential relevance to the present research are summarised in Table 2.20.

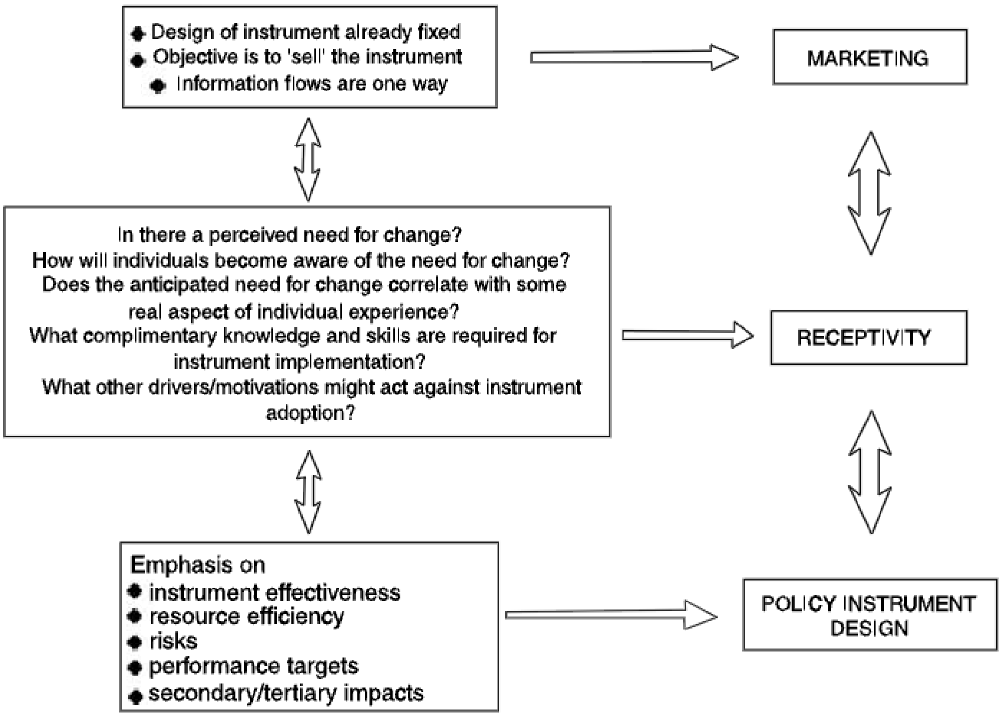


Figure 2.28 The position of receptivity between policy and marketing (Jeffrey and Seaton, 2004)

Table 2.20 Demonstrating the relevance of the receptivity framework to RWH

Attribute	Specific issues in water recycling (Jeffrey and Seaton, 2004)	Specific issues in RWH/present study
Awareness	Wastewater treatment processes; recycling technologies	Water supply/surface drainage; RWH technologies
Association	Impact of water reuse financially and for river flows	Water resource limitations; flooding
Acquisition	Information on recycling or purchasing equipment and its cost	Information on RWH or purchasing equipment, installation and its cost
Application	Maintenance requirements; Possession of skills required	Maintenance requirements; Possession of skills required

It is clear from Table 2.20 that the receptivity framework is potentially highly relevant to research into stakeholder capacity and RWH. The framework clearly identifies how and why receptivity could be compromised and thus how supporting initiatives might be designed (for example, in using it to design a questionnaire or in developing the CIPHE Greenplumb scheme). However, Jeffrey and Seaton (2004) do recognise the primary limitation of the framework, that being the model itself provides no answers, merely the conceptual means to delineate thinking regarding barriers to policy operalisation.

Brown and Keath (2007), in discussing the relevance of the framework to SWM, note that previous research on stormwater quality focused on distinct phases of receptivity in isolation, such as awareness (education programmes), application (prescriptive requirements in planning codes) *or* acquisition (capacity building). They assert that the value of the framework is in representing *all* of the attributes and it is therefore crucial that the present research addresses this, as far as practicably possible.

2.4.2.4 Self-efficacy, Social Identification and Social Representations

In addition to the receptivity of stakeholders to emerging niches, it is important to consider the way beliefs and attitudes are formed, in order to effectively demonstrate why changing them is important. Self-efficacy theory takes the view that the belief of a person about their ability to adjust exerts an impact on their motivation. That is, if someone thinks they cannot do something, their enthusiasm for undertaking the action will be compromised (Sefton, 2009). In this respect, individual perceptions of ability are crucial, as are the wider beliefs of the group with which the individual identifies.

Social identification theory places the individual within a group, or more accurately, aims to determine how the individual comes to relate to 'their' group. It determines that different internally driven, rather than external, processes filter information about the relevance of behaviours, which reinforce their group identity. Consequently, stakeholder groups are not homogenous and this results in policy instruments affecting different groups (and individuals) in different ways (Sefton, 2009).

However, when social norms (accepted behaviours) require conformity, different levels of acceptance may exist. For example, the group may internalise the norm by agreeing with and acting upon it. Or they may comply with the norm, by acting on it but not necessarily agreeing with it. This internalisation or compliance may be dependent on the level of relevant information in the possession of the group or the situation being too complex and the group requiring external guidance. If this guidance is provided and capacity enhanced the acceptance of a technology is likely to be greater (Rajabu, 2005). The factors most influential in this information and guidance process are credibility, integrity and consistency (Sefton, 2009). Renn *et al.* (1993) also highlight that social acceptance is closely aligned with perception of fairness – a technical response is unlikely to be well received if the implementation process is regarded as unfair.

Social representations theory delves further into understanding the complex network of beliefs, knowledge and practices held by groups i.e. the outlook, position or attitude a group takes towards a particular issue (Sefton, 2009). This depends on the existing ‘common sense’ and how this changes in response to external influences. Two processes are crucial in this process, those being anchoring (making a new common sense familiar to a group) and objectification (increasing the tangibility of the new common sense to the group).

For example, the policies and strategies outlined in Section 2.2 represent the UK government’s current position and attitude towards water management. These strategies have been developed from the assimilation of information via a network of academic and industrial organisations performing research on SWM. The research provided anchoring and objectification points, by demonstrating the relevance of SWM to emerging pressures (increasing demand and flooding), via the use of modelling and demonstration systems. What would previously have been novel information, for example the use of SUDS, has now become tangible, well established and absorbed into current thinking and policy. It could be argued that the common sense is changing from being focused on conventional piped systems to SWM techniques.

Renn *et al.* (1993) developed a three-step procedure to public participation, which took a hierarchical approach including aspects of self-efficacy and social representations. The procedure involved high-level stakeholders, experts and citizens. It was shown that the experts did not display a high level of empathy of the citizens concerns i.e. the experts did not adequately assess the values and concerns of the citizens. This particular study highlighted the importance of citizen panels and policy consultants in increasing knowledge of public preferences by policy makers.

For RWH, the three theories outlined in this sub-section present a unique perspective on viewing the system 'user' and potential users. Self-efficacy informs us that to motivate receptivity, stakeholders must find RWH to be relevant to them. Social identity theory tells us that internally driven processes are important in accepting new norms, which the group may or may not agree with. Providing relevant information *and* external guidance may facilitate internalisation of new norms. Therefore the provision of these could be considered in relation to social representations when investigating RWH.

2.5 Chapter Summary and Implications

2.5.1 Summary

This chapter has provided an extensive review of literature regarding SWM and RWH at both national and international scales. It has also provided discussion on several theories and frameworks from social theory, which may be applicable to the study of RWH in the UK. Through this comprehensive review it has been possible to complete the first two objectives of the research and their associated research questions:

- **Objective 1:** Identify drivers for promoting RWH:
    - What are the reasons for promoting RWH in the UK?

The main drivers for RWH in the UK are an increasing water demand, a perceived increase of flood frequency and a need to increase the adaptability and resilience of water infrastructure in the face of climate change and population growth, by implementing appropriate alternative technologies. It has been identified that RWH has the *potential* to act as both an alternative water supply and a stormwater source control device; therefore it could be well placed to assist in lessening the impact these issues. Peripheral benefits associated with RWH, include savings on water and effluent charges for system owners and reduced reliance on the centralised WDS. Other uses identified at the international level, which could be seen as presenting wider benefits, include fire fighting and reducing the heat island effect. A further benefit, which has yet to be fully explored, is the impact of RWH on peak demand reduction from domestic buildings on the WDS.

- How is RWH being promoted in the UK?

Comparison with the international leaders of RWH implementation has identified that RWH in the UK is potentially in a transitional phase. A number of policy instruments (such as the CfSH and BSI 8515:2009) now promote and support its (appropriate) installation. Additionally, some stakeholders (SMEs) are being encouraged to consider the technology (Envirowise's leaflet) and are supported with indirect financial support (via the ECA scheme). However, there is little indirect or direct support (such as subsidies) for other stakeholders, such as householders, in comparison with the other countries considered (Japan, Germany and Australia). Additionally, it is not being embedded in initiative which focus on adaptation to climate change.

- **Objective 2:** Establish known and unknown barriers and knowledge gaps:

Despite the undoubtedly positive promotional steps the UK government is taking towards RWH, the literature review suggests that these actions are limited to encouragement rather than enabling the implementation of systems.

- What are the known barriers/knowledge gaps for RWH in the UK?

Although a range of barriers to RWH in general have been identified, those specifically relating to the UK include the low price of water and high price of RWH systems, the perceived abundance of water, unfamiliarity with the unconventional, capital outlay, potentially long payback periods (depending on the efficiency of the system design), operation and maintenance difficulties, a shortage of specialists and health and safety fears. Additionally, although the potential of RWH as a flood risk alleviation measure was highlighted by modelling studies, there remains limited *empirical* evidence for this benefit, which could pose a major barrier to its acceptance in this regard. Unfortunately further empirical study of this function was beyond the scope of the present study.

In relation to health and safety fears, the lack of data on RWH systems in the UK does nothing to alleviate the concern and worries that stakeholders considering RWH may have. The literature review did not identify any studies regarding UK stakeholders' perceptions of risk from RWH (though GWR studies were identified) and only limited studies of water quality analysis or health-based assessments of RWH systems. This represents a significant knowledge gap and more pilot studies are required.

A further knowledge gap has been acknowledged as the limited testing of RWH design tools with empirical data, to assess both the tank sizes generated and the level of water saving efficiency estimated, as well as the life cycle costs associated with capital outlay and maintenance provision. Confidence in both of these variables is important for overcoming the barriers relating to uncertainty of payback periods and system efficiency. Assessing the tank size of a RWH has also been highlighted as being crucial for reducing capital system costs.

Furthermore, the review of RWH in the UK has identified that very little has been done with regard to public awareness of RWH. Consideration of social theory has highlighted that there is limited research on the receptivity, attitudes and willingness of stakeholders to implement RWH, as well as their ability. For example, the provision of financial incentives in other countries has been fundamental in achieving widespread implementation of RWH and was identified in one study as the primary reason for adoption. However, there is a lack of data on the importance of this measure to UK stakeholders. Also, the efficacy of current support or incentives for SMEs has not been assessed. Previous non-UK studies have implicated a range of factors as being important for the considering RWH, but these are as yet unexplored in the UK context.

- What are the *potential* barriers/knowledge gaps for RWH in the UK?

This research question was primarily to be answered by data collection activities presented in other chapters of the thesis. Therefore these will be covered further in chapters 3 to 7. However, the literature review has identified several potential barriers and knowledge gaps.

It has been highlighted that RWH is not a ‘fit and forget’ technology and requires a certain level of monitoring and maintenance. However, previous studies have not investigated the knowledge or willingness of stakeholders to conduct maintenance activities. As this is a vital part of system ownership, such information is critical to prevent maintenance becoming a significant barrier to implementation. In addition the suitability of RWH systems currently utilised in the UK has not been investigated and it is not known whether these are posing a barrier to implementation for stakeholders.

A significant potential knowledge gap identified is the lack of research on RWH in *non-domestic* buildings, especially in the UK. For example, limited system monitoring or non-potable demand data exists for non-domestic buildings. Availability of such data not only limits the representation of non-domestic demand in the calculation of system designs, but also in the assessment of the impact of RWH on peak non-domestic demands and consequently the WDS design and costs for non-domestic developments (such as large office complexes or industrial/retail parks).

A further significant gap in knowledge is of empirical data regarding the source control and flood alleviation function of RWH: limited evidence was identified that quantified the multi-functional benefits asserted by a number of studies. Unfortunately addressing this knowledge gap was beyond the scope of the present study, due to the range of other knowledge gaps already being addressed and the resources available.

2.5.2 Implications for the Research Design

Summarising the drivers, barriers and knowledge gaps for RWH in the UK reveals that there are technical (lack of testing of design tools, uncertainty regarding water quality, lack of demand data for non-domestic buildings), social (receptivity of stakeholders, efficacy of current support) and financial (capital and operational costs) aspects for which additional research is required. The latter is considered within this study, where possible, when data is available and is considered in relation to the two former aspects, as financial concerns generally relate to technical or social phenomena. However, detailed financial analysis is beyond the scope of the present research.

Keeping this in mind, the objective of the following four chapters is to collect data to address the barriers and bridge the knowledge gaps identified. This applies the third objective of the research, which is to:

- **Objective 3:** Enrich the socio-technical evidence base relating to RWH in the UK.

A framework of social theory research has been identified from the literature, which is summarised in Figure 2.29. This framework influences not only the approach taken in the following chapters, in terms of the methods and stakeholders selected, but also the way in which the data from the technical and stakeholder data collection chapters is analysed.

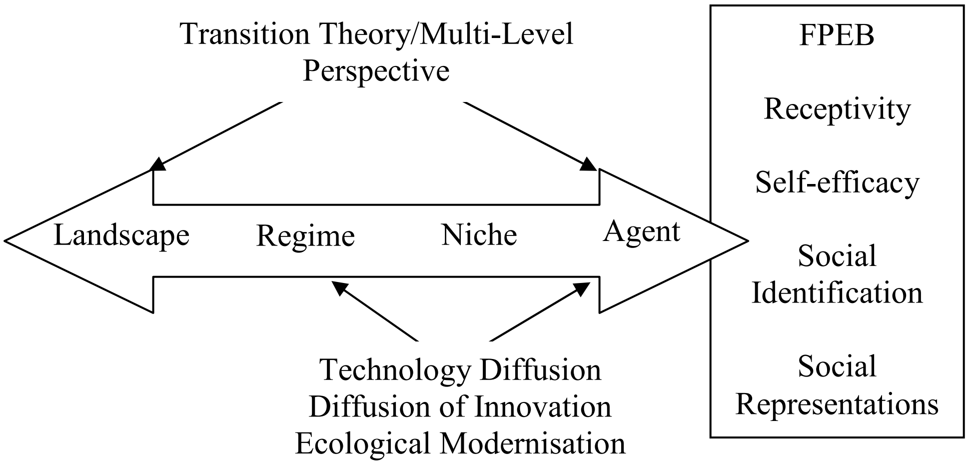


Figure 2.29 The social research theoretical framework developed in this thesis

2.5.3 Justification of Stakeholder Group Selection

Discussion throughout the literature review has highlighted RWH is relevant to a number of stakeholder groups and these should be differentiated when examining receptivity for policy or support instrumentation design and implementation. Consequently it was decided to select three stakeholder groups to investigate. This seemed feasible within the research timescale and resource availability. The three groups selected were SMEs, householders (including office tenants) and architects. The selection of these groups was based on a number of criteria, as follows.

2.5.3.1 SMEs

In order to be described as a SME, a European business must meet the following criteria determined by the European Commission (EC, 2005):

"*The category of micro, small and medium-sized enterprises (SMEs) is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding 50 million euro, and/or an annual balance sheet total not exceeding 43 million euro*."

Figure 2.30 outlines the levels of headcount, turnover and annual balance sheet totals that correspond to whether an SME is determined to be micro, small or medium-sized. SMEs provide a large percentage of global employment – in the EU alone it is estimated that 66% of employment is in the micro and SMEs sector (Lukacs, 2005). In the UK SMEs represent 99.1% of all enterprises, accounting for 59.4% of private sector employment and 50.1% of turnover (DBIS, 2009). For 2008, employment in SMEs was estimated at 13.7 million, an increase of 2.1% from 2007. Additionally, turnover for 2008 was 4.2% higher than in 2007. As such SMEs represent a huge economic sector (as well as the buildings and infrastructure they require), which maintained growth prior to the recession that commenced in January 2009 (BBC, 2009).

SMEs usually operate in the service, trade, agri-business and manufacturing sectors, sectors, which can also demonstrate high water usage. For example, the textile sector can use 80-100m^3/tonne of finished fabric (Li Rosi *et al.*, 2007). SWM techniques, such as effluent reuse or RWH, can provide dual benefits. Overheads, such as water or discharge costs, can be reduced and the impact of high consumption (and subsequent treatment) on the water resource of an area can also be reduced.

Enterprise category	Headcount: Annual Work Unit (AWU)	Annual turnover	or	Annual balance sheet total
Medium-sized	< 250	≤ €50 million (in 1996 € 40 million)	or	≤ €43 million (in 1996 € 27 million)
Small	< 50	≤ €10 million (in 1996 € 7 million)	or	≤ €10 million (in 1996 €5 million)
Micro	< 10	≤ €2 million (previously not defined)	or	≤ €2 million (previously not defined)

Figure 2.30 categories of definition for SMEs (EC, 2005)

SMEs are also arguably incentivised to implement rainwater harvesting (RWH); they qualify for the ECA scheme and can potentially save substantial amounts on their water bills (as well as benefitting from the potential ‘green’ kudos of such technologies). In 2008 the Carbon Trust announced a £31 million loan pot available to SMEs for energy efficiency measures, with the largest loan available being £200,000. Due to the emerging links between energy and water, it is possible that such funds will be extended to water-based measures. Despite these benefits, the uptake of alternative or decentralised water resources amongst SMEs has been limited to date (Li Rosi *et al.*, 2007) and they have not featured in previous research on RWH.

2.5.3.2 Householders

Recent policy, including the CfSH is likely to result in the greater consideration of RWH implementation by housing developers. This is in response to requirements for developments to reduce their water consumption (to 125 l/person/day) and their impact on the natural drainage of a site to reduce the risk of flooding (DEFRA, 2008d). The construction of new homes means that potentially a third of the housing stock will be built between 2006 and 2050 (DCLG, 2006a). Consequently, a significant amount of these households may have RWH installed.

By implication, the remaining two thirds of the housing stock is represented by the existing housing stock, which will still be in use in 2050. Therefore retrofitting of SWM measures (such as WSDs and RWH) is likely to increase in line with ambitions to improve water efficiency in these buildings through appropriate refurbishment (DCLG and DEFRA, 2006).

In order for RWH systems installed within new build and renovated housing to operate efficiently, incoming tenants and owners will need to be informed about their use and maintenance (Rajabu, 2005; Neke *et al.,* 2009). It is therefore crucial that the receptivity of this stakeholder group is assessed in order to build capacity at this level. In terms of current support and incentives for householders and RWH, these are limited and therefore the primary direct benefit to this group is through reduced water bills (which will be variable depending on WSP area). Further information regarding the appropriateness of other indirect or direct support instruments would be valuable for future policy development.

2.5.3.3 Architects

As highlighted in Section 2.4.1 building construction professionals have featured in previous research on stakeholder aspects of RWH system implementation. However, before a RWH system can be installed into a new building it must be designed into the building's fabric. One stakeholder group at the pre-installation phase of the RWH installation process that has not featured in previous research is the architect.

The initial design (and pre-design) stage of a building is undertaken by an architect based on the information (often called a 'brief') they are given by a client (ARUP, 2005). If the client requires certain sustainability or water demand management features or performance, the architect may need to consider alternatives to appliances such as standard WSDs. For example, if the client wishes to achieve CfSH level 5 or 6, RWH is likely to be required. Additionally, if a BREEAM (or similar) rating is desired the architect will need to consider measures relating to this in the design to ensure the building's water consumption and/or reuse is appropriate.

Consequently the knowledge and awareness of the architect (or architectural practice) regarding water management issues will be an important factor in the building *and* RWH system design process. Research has shown that when RWH systems have been specified within a building, the building's features are not necessarily considered at the design stage in relation to the performance of the RWH system (Forster, 1999; Ward *et al.,* 2010a). Therefore an assessment of the knowledge and awareness of RWH is made within the present research, along with information gathering regarding current practice.

Conceptually, these stakeholder groups represent different places along the receptivity and ability spectrum. The first group appears to be fairly well supported, whereas the second is not and the last is potentially only motivated by the requirements or aspirations of their client (and compliance with the relevant building related policy and standards). Investigation of these groups therefore presents an opportunity to assess the efficacy of SME support, provide scoping research for the types of support mechanisms potentially appropriate to householders, as well as assessing the current ability of architects to incorporate RWH systems into building designs.

The following chapters describe the methods used, the data collected and the analysis undertaken, which form the main body of the thesis. Chapters 3 and 4 describe construction of the stakeholder evidence base and Chapters 5 and 6 the technical evidence base.

3 CHAPTER 3: UNDERSTANDING STAKEHOLDER RECEPTIVITY – HOUSEHOLDERS, OFFICE TENANTS AND ARCHITECTS

3.1 Introduction

The preceding literature review identified that there is a significant knowledge gap in understanding of the perceptions and experiences (receptivity) of stakeholders. Objective three of the thesis is to enrich the social knowledge base regarding RWH in the UK. Therefore this chapter aims to answer the following research question, which focuses on the receptivity of householders and office tenants:

- Is the UK public aware of and willing to implement RWH?

The chapter describes the implementation of a survey on RWH systems to four study samples – two of which are RWH system users and two of which are non-users. The chapter is divided into the following sections:

- **Survey Method;**
- **Results and Discussion;**
- **Questionnaire to Architects;**
- **Chapter Summary and Key Messages.**

Additionally, the primary research question for this chapter was broken out into a series of sub-questions, in order to appropriately structure the questionnaire administered during the survey. These sub-questions are:

1) Are participants' aware of water saving devices in general?

    a) Do they have awareness of or experience with RWH?

2) How acceptable are a proposed range of sources and end uses?

    a) What risk value do participants assign to these?
    b) Do these differ between users and non-users?

3) From where (if anywhere) do/have participants source/d information on RWH?

    a) Where do participants' view the most appropriate place to obtain information?

4) What factors are most important for encouraging consideration of implementing RWH?

    a) How do they rank?

    b) Do these differ between users and non-users?

5) What are participant's views of RWH?

    a) Do they think RWH is a good thing?

    b) How aware are participants' of maintenance issues?

    c) What are the perceived benefits and disbenefits of RWH?

    d) Do opinions or knowledge differ between RWH system users and non-users?

    e) How do users rate the performance of WCs flushed with RWH?

A supplementary survey was undertaken with architects, in order to determine the level of expertise and knowledge held within such practices. However, due to a particularly low response rate, the survey did not provide the insights it was hoped to attain. Therefore the survey is discussed at the end of this chapter, rather than in a dedicated chapter. The research question in relation to the survey was:

- Are building design professionals aware of RWH and the appropriate design documentation associated with it?

3.2 Survey Method

In order to answer the research questions posed, to gain a broader insight into the perceptions of and experiences with RWH of system users and non-users, a questionnaire was designed and implemented. This was undertaken in two parts: part one consisted of a pilot study and part two was the principal study. The author recognises that multiple in-depth interviews would have permitted greater exploration of the social and contextual situation of the participants. However, both resources and logistics prevented such a methodology from being undertaken, although measures were taken to accommodate these perspectives as far as possible (conducting follow-up interviews). The questionnaire was designed and implemented during the same period as DEFRA's Framework for Pro-Environmental Behaviours (DEFRA, 2008a). Therefore the segmentation approach devised in that framework was not used in the questionnaire design. However, this is perhaps beneficial, as it allowed the subject of RWH to be explored with participants without the constraints of a newly emerging approach. The present study could potentially act as a scoping study for future work on applying segmentation to stakeholder perceptions of and experiences with RWH, by identifying if different stakeholders have differing requirements.

3.2.1 Ethical Issues

In conducting research involving human participants, one of the most important issues is that of ethics, that being the prevention of a breach of human rights or inappropriate induction of anxiety or other impact (Robson, 2002). What is and what is not ethical is a difficult thing to decide and, in the context of research, this decision is usually the responsibility of an ethics committee. Ethical practise usually involves the following of a code or set of principles laid down by such a committee (Oppenheim, 2005).

For the present study the appropriate ethics committee was that within the School of Engineering, Computing and Mathematics at the University of Exeter. The ethics policy within the School required the submission of a project ethics proposal where both University and non-University individuals may be involved. This was inline with requirements of the British Psychological Society and included points on anonymity, confidentiality and withdrawal (BPS, 2006). The proposal must outline potential ethical issues posed by the research, along with a protocol of actions to overcome these issues.

Ethical issues that arose in the present study mainly related to the anonymity and confidentiality of participants responses and personal information (such as age, gender and employment status). With respect to this standard confidentiality and data protection statements were provided on all online and paper-based questionnaires. The researcher's contact and website details were provided on cover letters and inside the cover of the paper-based questionnaires. This allowed transparency of the researcher as well as increasing potential for contact, if participants had concerns or issues requiring clarification. Permission from interviewees was secured before an interview commenced and reassurance given that anonymity would be maintained. Furthermore, all interview transcripts were approved by the interviewee concerned. In terms of storage, all materials relating to the study participants were kept locked within appropriate facilities at the University (either physically (under lock and key) or electronically (password-protected)). The completed and signed ethics form for the research undertaken within this thesis is located in Appendix B.

Ethical issues in research apply not only to conducting the research, but also to the reporting of results (Oppenheim, 2005). Therefore standard procedures on ensuring anonymity within the results and discussion chapters of this thesis were followed. For example, interviewees are referred to in terms of their transcript number. Although this slightly depersonalises the interviewee, it ensures anonymity of both the interviewee (and in the case of SME interviews the company in question).

3.2.2 Questionnaire design and construction

Within both the pilot and principal studies the questionnaires were designed and constructed using the Advanced Psychometric and Reaction Test, 'APART' software (Dart, 2007), (Figure 3.1). APART allows construction of a bank of 'stimuli' (questions) and 'responses' (answers), which can be used to generate online (and subsequently paper-based) questionnaires. The bank of questions is particularly useful if the same questions or a different combination of questions are to be administered to different participant groups. In the pilot study responses were recorded in relation to over 140 items pertaining to RWH and water resources.

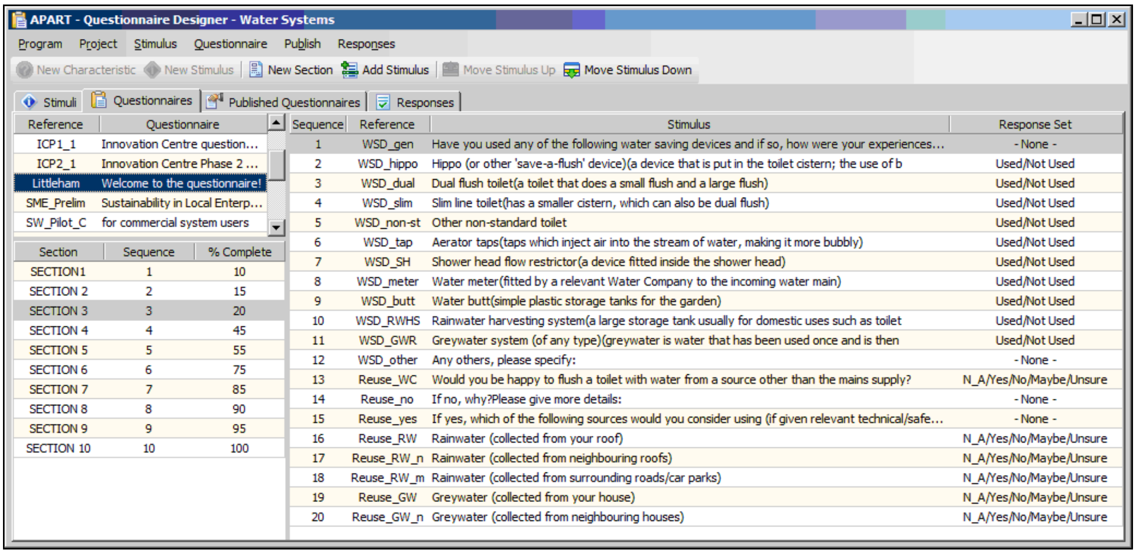


Figure 3.1 User interface of the APART questionnaire design software

Questionnaires were administered using both an online interface (Figure 3.2) and a paper-based version. Multiple-choice 'drop-down' menu response sets were constructed within APART to enable participants to quickly and simply answer each question. Generally these consisted of 'Yes, No, Maybe, Unsure, Not Applicable'. However, there were some question-specific response sets, such as 'Used-positive, Used-negative, Used-mixed' for a question on prior experience with water saving devices. Likert-type scales (responses along a pre-determined spectrum) were used to assess risk, in line with Hurlimann (2007b), where 1 indicated the least risk and 10 indicated extreme risk.

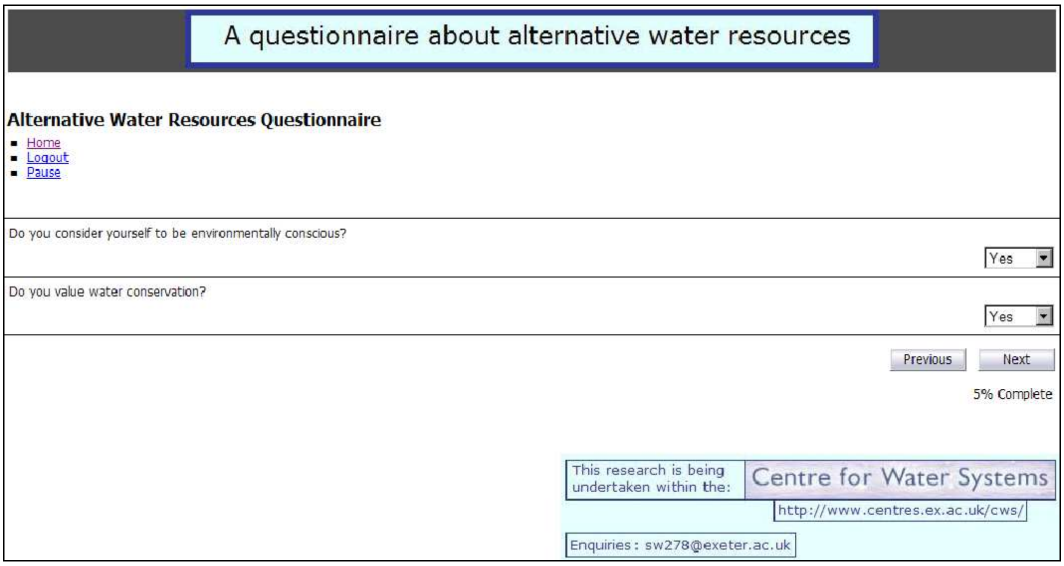


Figure 3.2 Participant interface for the questionnaire

Where there existed the potential for an unanticipated response to be used, an 'Other, please specify' open-ended response was provided, to ensure that no unanticipated responses were missed. The response sets created in APART were replicated on the paper-based version in the form of tables, where participants were asked to tick the box that applied to them. An abundance of 'text boxes' were included (usually at the end of a section) to allow participants to add any comments they felt were relevant, but for which there were not appropriate questions or answer sets (i.e. untheorised responses).

Confidentiality statements were included on both versions and individuals participating were reassured of their anonymity at the beginning of the questionnaire, as well as reiterating that all information gathered would be treated confidentially.

3.2.3 Pilot Study Execution

One of the most critical aspects of undertaking a questionnaire or survey is conducting a pilot study. This allows the researcher to trial different question formats, questionnaire layouts and approaches to delivery (Dilman, 1978; Robson, 2002; Oppenheim, 2005). The pilot work for the questionnaire design was divided into two parts. Firstly, a literature review was undertaken to identify the types of information the questionnaire should seek to illicit. In the case of existing questions from previous studies, caution was taken, as often these were conducted in different geographical locations (Australia for example) or different situations (where strong environmental (prolonged drought) and financial (rebates) incentives had been in place for a number of years). Therefore cultural applicability had to be considered (Oppenheim, 2005). However, perspectives from previous research (such as EM and DI from White, 2007) did influence the questionnaire design.

Secondly, a prototype questionnaire was devised, distributed and analysed, to allow issues that arose in the implementation process to be addressed before undertaking a full study. This second stage also included consideration of questionnaire delivery, based on the characteristics of the known main sample populations (such as geographical location or access to the internet).

From the literature review undertaken, questions were asked on a range of topics relating to water resources and RWH, including:

- Water saving devices - to obtain a perspective on prior experience with water efficient devices and alternative water sources (such as RWH and greywater recycling (GWR));
- Willingness to consider alternative water sources – RWH and GWR from different catchments and properties;
- Perceptions of risk associated with RWH uses – non-potable, sub-potable and potable;
- Awareness of types of and a willingness to pay for maintenance activities;
- Factors that would encourage consideration of implementation of a RWH systems;
- For system users - experiences with RWH systems and WCs flushed by these systems.

In addition, an introductory section was included that contained a diagram of a rainwater harvesting system and a brief explanation. This was provided so that participants who had not come across the technology before had an idea of what a system entailed before completing the questionnaire. The introductory section also included general questions on participants opinions, such as ‘Do you think rainwater harvesting is a good thing?’

Standard demographic questions, such as age, gender, occupation, educational status and home ownership status were included (in both the pilot and the principal study). This was to primarily assess the demographic characteristics of the samples, rather than to provide comparison between different demographic groups. Previous studies (including those described) on environmental behaviour have attempted to correlate an individual’s demographic factors with attitudes, perceptions and behaviours. However, such studies can often prove inconclusive (Barr, 2002). Additionally, this study aimed to identify general perceptions on accepted uses, sources, maintenance costs, activities and experiences with systems, not demographic-specific themes. Therefore demographic comparison or correlations are only presented where they are deemed appropriate, otherwise demographic results are presented merely to illustrate the characteristics of the populations sampled.

The pilot questionnaire was administered during April and May 2008 in two ways:

1) By sending a link to the online questionnaire to a single contact within a particular organisation who then forwarded it to participants;

2) By sending paper-based versions, with a cover letter, to a single contact within a particular organisation who then forwarded them to participants.

Organisations were contacted before the questionnaire was sent, to explain the background to the research and to hopefully maximize the response rate (Robson, 2002). In the case of the online version, the link was accompanied by a group-unique 'batch' login code and password. This enabled the responses of the different organisations to be differentiated, in order to facilitate comparisons between groups at a future juncture. The organisations contacted all had a potential vested interest in water-related research (some initial contacts were known to the researcher) and were contacted in order to get as much feedback on the terminology and structure used within the questionnaire as possible. Organisations contacted included a national charity, a human resources company, an accountancy software company, a rural housing association (19 residents with RWH systems were surveyed), a water company, a RWH system supplier, a University department and an engineering consultancy (which utilised RWH in its office).

A deadline of one month from the date of the email/cover letter to the participating organisations was given. This set a timeframe for the participants to respond and for the researcher to maintain control over the research programme. The 'contact and collect' methodology (Barr and Gilg, 2007) was not utilised for the paper-based version, for both resource and logistical reasons (some participants were based on the Isles of Scilly for example). When paper-based competed copies were received, the researcher entered the responses into the electronic database, to facilitate later data analysis. As the link to the online questionnaire was sent to a contact within different organisations and then forwarded to participants, rather than being sent to a set number of individuals, a response rate could not be ascertained. However, the number of respondents that completed the pilot questionnaire within the allocated duration was 46. This was deemed to be sufficient for a pilot study, inline with White (2007).

3.2.3.1 Pilot Study Results

The pilot study was a useful exercise in many respects. Firstly, it identified preliminary indicators of perceptions associated with RWH systems, which determined that the types of question included were indeed eliciting required and useful information. Secondly, the additions, notes and comments made in relation particular response sets allowed these to be ‘fine tuned’ for the principal study. Finally, useful feedback and pointers on the actual questionnaire structure and content itself were given, which permitted refinement of the final questionnaire before the full study. For example, participants found the questionnaire too long. To address this, the number of items on the questionnaire (which in the pilot was just over 140), was reduced to 90 and 114 in the principal study (for users and non-users respectively).

Oppenheim (2005) warns against using pilot study findings as workable results, suggesting that the likelihood of pilot samples being representative is limited. However, in the present pilot sample populations were as close to the principal study sample population as was feasible to achieve (i.e. it included both RWH system users and non-users). Therefore some of the questionnaire results were analysed using standard descriptive statistical techniques. Inferential statistical testing was not undertaken however, due to the limited sample size and the need to re-conceptualise some questions based on the feedback of participants.

Results illustrated that in general participants were aware of and had experience with a range of water saving devices, but that experience with more technically complex water saving devices/alternative water sources was limited. Participants showed a positive response to consideration of the use and implementation of a RWH system. However, when asked to consider different collection sources other than their own roofs, responses were less favourable. It was also ascertained that the risk associated with a particular use increases as the use becomes increasingly personal. In terms of maintenance activities, participants demonstrated an underestimation of the recommended frequency and cost for conducting maintenance. Of the consideration factors presented to the participants, a large proportion selected the availability of a grant or subsidy as the item which would most likely encourage them to consider installing a RWH system (Ward *et al*., 2008).

3.2.4 Principal Study

Post-pilot refined questionnaires were administered during November 2008 using both online and paper-based versions. Table 3.1 provides a summary of each section of the questionnaire. Implementation procedures were very similar to those for the pilot study and so will only be discussed where something was different or notable. Larger sample populations were sought for the principal study and these are described in the following section.

Table 3.1 Summary of the sections within the finalised questionnaire

Section	Topic	Coverage (%)
1	General – definition, use of RWH	10
2	Environmental inclination	5
3	Water saving devices	5
4	Potential sources, uses and risk associated with RWH	25
5	Perceived benefits of RWH systems	10
6	Factors affecting consideration of RWH implementation	20
7	Maintenance (activities and cost) of RWH systems	10
8	Ease of use of RWH systems	5
9	Personal demographics	5
10	Feedback and future research participation	5

3.2.4.1 Participant groups

Convenience (purposive) samples were used, as administering the questionnaire to RWH system user's required prior knowledge of developments where such systems were installed. Both in the UK, the newly completed Broadclose housing development (BC) in Bude, Cornwall (Figure 3.3) and the Innovation Centre Phase 2 (ICP2) office building at the University of Exeter, Devon (Figure 3.4) were chosen, as both developments utilise RWH (Ward *et al.*, 2008). Locations with similar characteristics, but without RWH systems, were identified to represent the non-user participant groups. These were the Littleham housing development (LH) in Exmouth, Devon (Figure 3.5) and the Innovation Centre Phase 1 (ICP1) office building at the University of Exeter (Figure 3.6). The locations of these developments are illustrated in Figure 3.7 and their characteristics are summarised in Table 3.2.

For BC a list of street names and house numbers was obtained from the Guinness Trust, one of the organisations responsible for its construction (the others were North Cornwall Housing Association and Midas Homes). This allowed estimation of the number of paper questionnaires to be estimated (as the list also provided details of unoccupied houses). A similar list was not available for LH and therefore reconnaissance activities (walking round the estate) were undertaken to determine the street names and numbers from which to estimate the number of paper questionnaires required.

Table 3.2 Summary of characteristics for the questionnaire sample locations

	ICP1	ICP2	BC	LH
Location	Exeter	Exeter	Bude	Exmouth
Type	Commercial	Commercial	Residential	Residential
Population	~35	110 (capacity = 300)	173 houses	145 houses
RWH?	No	Yes	Yes	No
Approx year of construction	2000	2007	2008	1950
Type of RWH system	NA	Single	13 communal	NA
RWH system application	NA	WC flushing	WC flushing	NA

It was known that potential participants within the two Innovation Centre buildings had access to internet facilities; therefore an email link to the online questionnaire was sent by the Centre's administration team to occupants of both buildings. As knowledge of access to internet facilities did not exist for either the Broadclose or Littleham developments, a paper-based questionnaire was administered, with an option for online completion if preferred/appropriate. In both cases, the email link was accompanied by a location-unique login code and password. This enabled the completion rates of the locations to be differentiated, so that response rates for each location could be determined, as well as permitting future group comparisons, if deemed appropriate. The paper-based questionnaires were hand delivered, primarily to ensure they reached the intended recipient. Again, the 'contact and collect' methodology (Barr and Gilg, 2007) was not utilised for both resource and logistical reasons. Included with the paper-based questionnaires was a cover letter introducing the context of the research and a stamped self-addressed envelope, so that the questionnaire could be returned as easily as possible with least inconvenience to the participant. Examples of the paper-based questionnaire manuscript (and cover letter) for RWH system users and non-users are located in Appendix B. Reference was also made to recycling the manuscript if it was not going to be returned, to maintain a coherent environmental message to the potential participant.

3.2.4.2 Follow-up

In February 2009, approximately 13 weeks after the questionnaires had been sent out; a second request to complete the questionnaire was delivered to all participants (either electronically or by hand). As the first package had made it as easy as possible for potential participants to complete the questionnaire, it was decided that providing a full questionnaire with stamped envelope a second time was not appropriate. This was primarily to prevent wastage of a large volume of paper, envelopes and stamps, should further encouragement not elicit a significant increase in response. It could be argued that if potential participants had intended to complete the questionnaire, they would have done so within the 13 weeks or would still have their copy but have not yet completed it. If the questionnaire had been thrown away/recycled, it inferred the potential participant had a low interest in completing it and therefore receiving a further copy would be unlikely to encourage them to complete it.

Therefore a cover letter (a copy of which is located in Appendix B) referencing the first posting was sent, with a request to complete any questionnaires that were still held, but that had not yet been returned. Included were thanks to those that had already completed their questionnaire and instructions to ignore the letter as it was a mass-posting, necessitated by the anonymous nature of the survey. Furthermore, a contact number for the researcher was given so that any interested participants could make contact to obtain a copy of the questionnaire – at no cost to them, with the exception of the phone call. Also given were the details of the online questionnaire, to facilitate additional online completions. Although no requests were made for paper-based questionnaires (and therefore the author would not necessarily advocate future use of this method), additional online completions were observed (including some from the LH location), which totalled 32% (34 out of 106) of the final number of participants.

3.2.4.3 Feedback and Follow-up Interviews

A final section on the questionnaire gave participants the option to receive feedback on the questionnaire and to put their name forward for further research. Reassurance was given that any contact details provided would only be used to contact them for these purposes. Further research took the form of a follow-up interview. These were undertaken in order to enhance the cultural relevance of the research by allowing participants to elaborate on their thoughts and opinions. Additionally, although not a primary aim of the research, the interviews permitted assessment of whether completing the questionnaire and receiving feedback had an impact on participant views of water or RWH.

25 participants included their details to receive feedback and were consequently sent a letter of thanks and a short report on a selection of the results felt to be most relevant, such as WC performance and maintenance arrangements. 13 participants put their names forward to participate in future research. Due to project timescales, half (6) of these participants were chosen at random, contacted by post asking if they would be happy to participate in a follow-up interview and given a period of 5 weeks in which to reply. Only 3 reply slips were returned; 2 from male participants agreeing to an interview and 1 from a female participant declining to take part on health grounds.

Short (20 minute), semi-structured telephone interviews (at the participant's request) were conducted with the two male participants (both from Broadclose), with themes focusing on the following areas:

- Promoting RWH within the UK;
- Current promotion of RWH within the UK;
- Did anything need to improve/change;
- Influence of the questionnaire on thoughts/actions.

Figure 3.3 The Broadclose development (the author; Google earth)

Figure 3.4 The Innovation Centre Phase II (the author; Google earth)

Figure 3.5 The Littleham development (the author; Google earth)

Figure 3.6 The Innovation Centre Phase I (Innovation Centre website; Google earth)

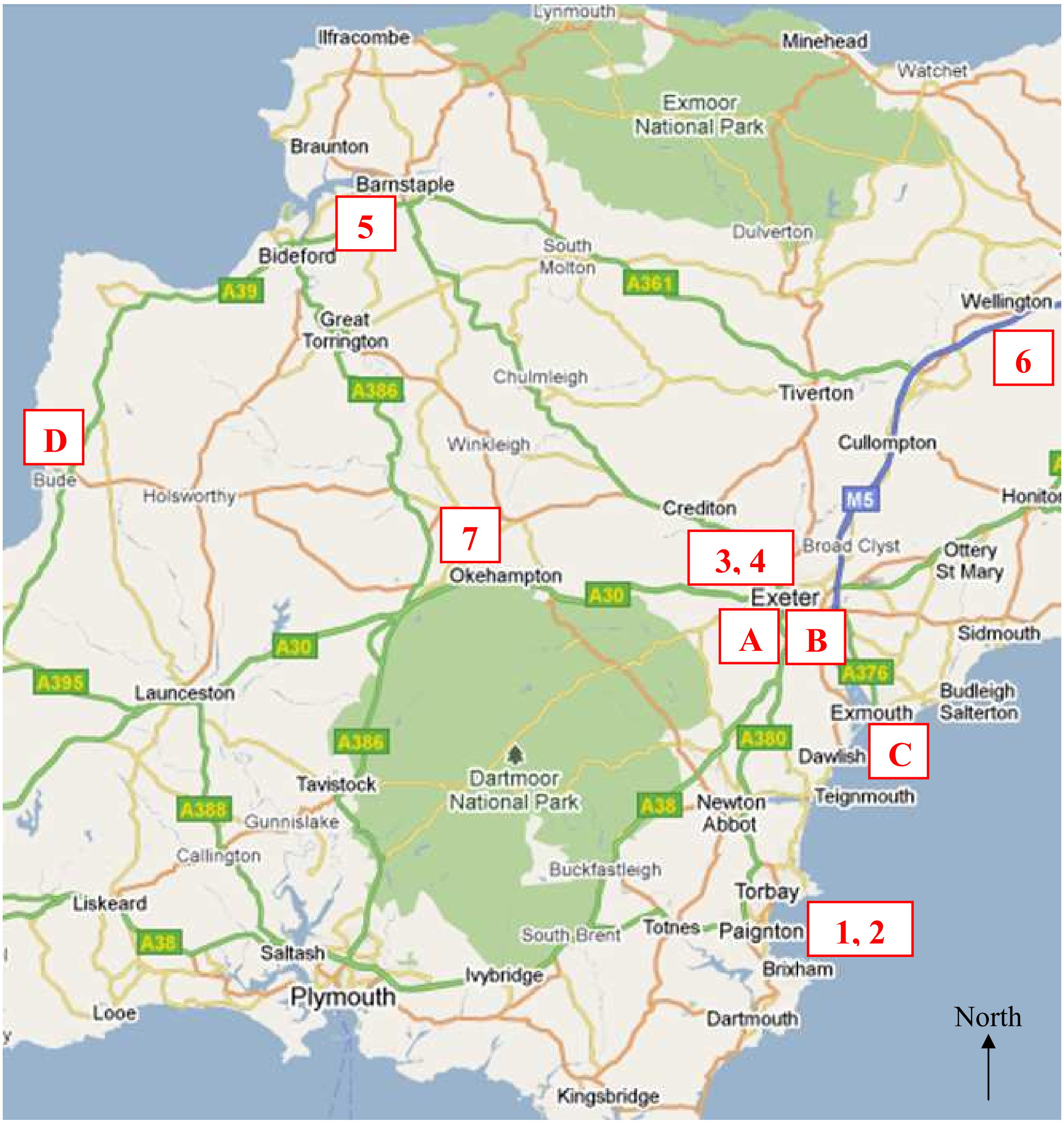


Figure 3.7 Map of questionnaire and interview locations (Googlemap; not to scale)

<u>Legend</u>

	Questionnaire Location		Interview location
A	Exeter – Innovation Centre, Phase I	1	Paignton – Farm/Shop/Cafe
B	Exeter – Innovation Centre, Phase II	2	Paignton – Animal charity
C	Exmouth – Littleham Development	3	Exeter - Office
D	Bude – Broadclose Development	4	Exeter - Hotel
		5	Barnstaple - Cafe
		6	Clayhiddon – Specialist craftsman
		7	Jacobstowe – Charity (with working dairy)

3.3 Results and Discussion

In the following sections, cooperation rates and demographics are discussed first. Results are then organised in sections relation to sequentially answering the research questions. Data was analysed using standard Excel techniques and when descriptive statistics showed trends worthy of further investigation, datasets were imported into the Statistical Package for the Social Sciences (SPSS) and the appropriate inferential statistical tests applied. The results are discussed in the relevant sections below and summarised at the end of the chapter.

3.3.1 Cooperation Rates and Response Bias

Questionnaire cooperation rates were determined by dividing the number of questionnaires received from a group, by the number of questionnaires issued (AAPOR, 2006). As expected, cooperation rates to the questionnaire were variable, depending on location (Table 3.3). The overall cooperation rate across the locations was 27%. This was identified as being acceptable for PhD research (Barr, 2009).

Table 3.3 Cooperation rates for each questionnaire location

Group	ICP1	ICP2	BC	LH	Total
Number sent	17	77	159	145	398
Number returned	16	19	44	27	106
Cooperation rate (%)	94	25	28	19	**27**

Full response rates (the number of completed questionnaires divided by the number of eligible questionnaires (AAPOR, 2006)) could not be determined, as these require data on incomplete or unaccounted for manuscripts. This includes the number of questionnaires that were delivered but not successfully received, for whatever reason. For example, although a list of houses that were unoccupied was available for BC (from the development management company), such a list was not available for LH (as there is no management company). In the case of emailed requests, it is possible that the email entered the recipient’s junk folder, was subsequently deleted and thus was not received. Therefore the number of questionnaires that were delivered *but not received* is not known and thus only cooperation rates could be calculated.

It has been observed that response rates have been declining for a number of years, with invasion of privacy and increasingly busy lifestyles often cited as the main reasons (White, 2009). This is perhaps not surprising in an age where anyone can go online and construct a questionnaire using a number of freely accessible tools (www.surveymonkey.com, for example). However, response or cooperation rates are useful for determining potential non-responses biases (Oppenheim, 2005). Response bias can be related to the predisposition of a person to respond to questionnaires in general, or to the subject matter in question. In following a purposive sampling design, it could be inferred that two of the sample populations (those with RWH) may have a potential response bias; that is they have direct experience with or an interest in the subject matter. However, as is reported in Section 3.3.3, some building occupants in ICP2 did not know there was a RWH system within their working environment. Therefore this assumed response bias does not necessarily apply in this case. Furthermore, as can been seen from Table 3.3, the cooperation rate of ICP1 (no RWH) was actually far higher and these participants did not necessarily have a direct interest in the subject matter.

3.3.2 Demographics

In terms of gender, the samples from each location were approximately equal, as illustrated in Figure 3.8. Additionally, age distributions were as would be expected from samples taken from employment and domestic environments, with the core of participants being between the ages of 21 and 60 (Figure 3.9). With regard to home ownership, only the participants in the domestic questionnaire were asked about their occupancy status. Home ownership between the two groups was approximately equal, although Broadclose showed a higher percentage of shared ownership (Figure 3.10). This is perhaps to be expected as Broadclose is a newly completed development and shared ownership schemes are a relatively new initiative introduced to assist those in areas where income to house price ratios are high purchase their own homes. There was also a difference between the percentage of participants in tenanted council and tenanted housing association homes. Again this is a function of changing initiatives; in recent years councils have retained ownership of fewer houses, instead utilising the management services of housing associations (more formally known as registered social landlords). Finally, Figure 3.11 illustrates the number of occupants per household. It can be seen that most households had two occupants, although there was a high proportion of single occupant households in LH.

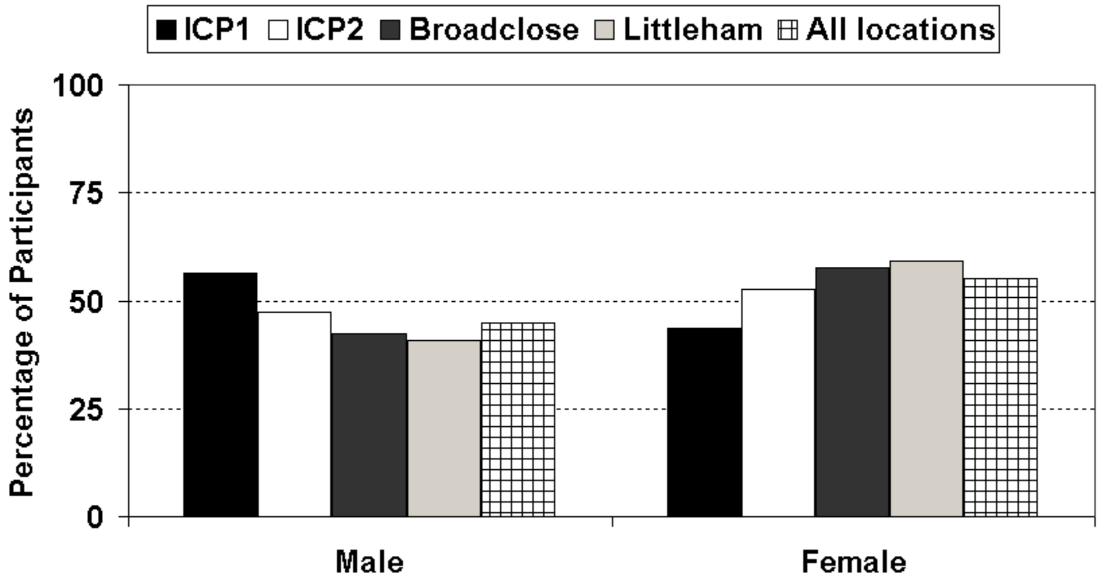


Figure 3.8 Gender of participants

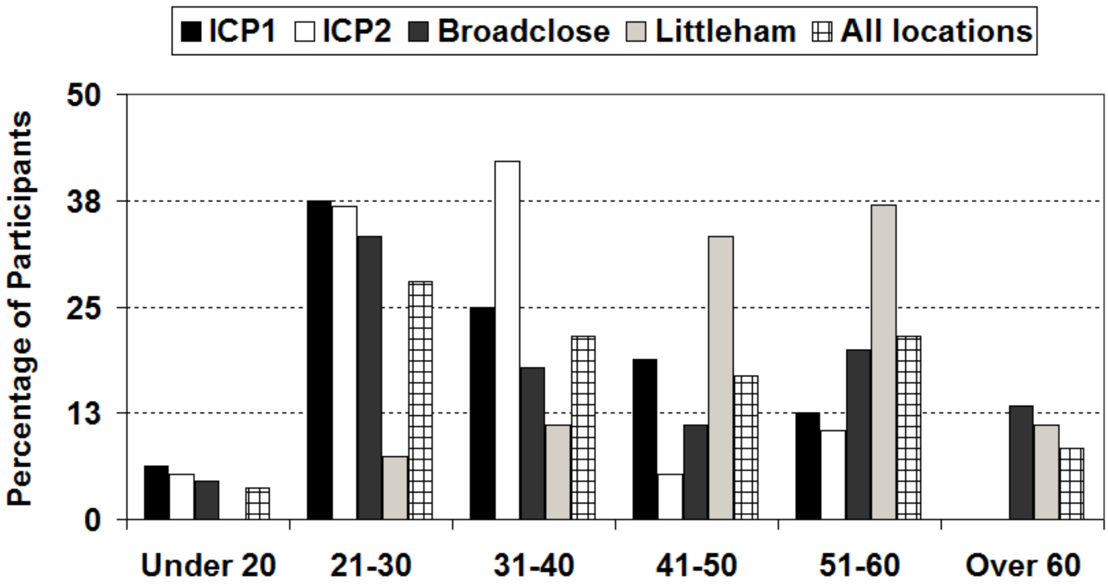


Figure 3.9 Age distribution of the participants

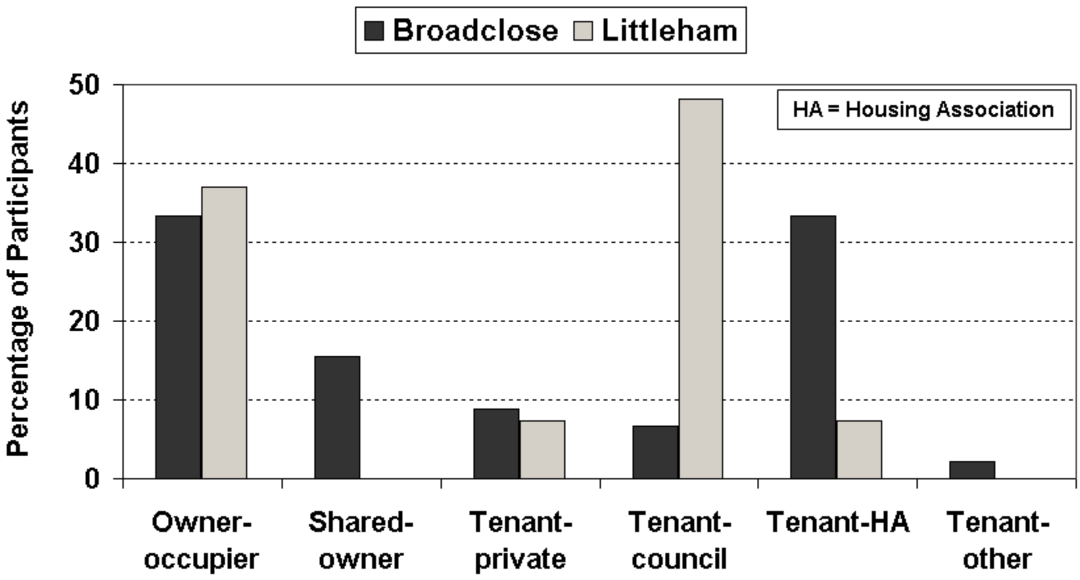


Figure 3.10 Occupancy status of residential location participants

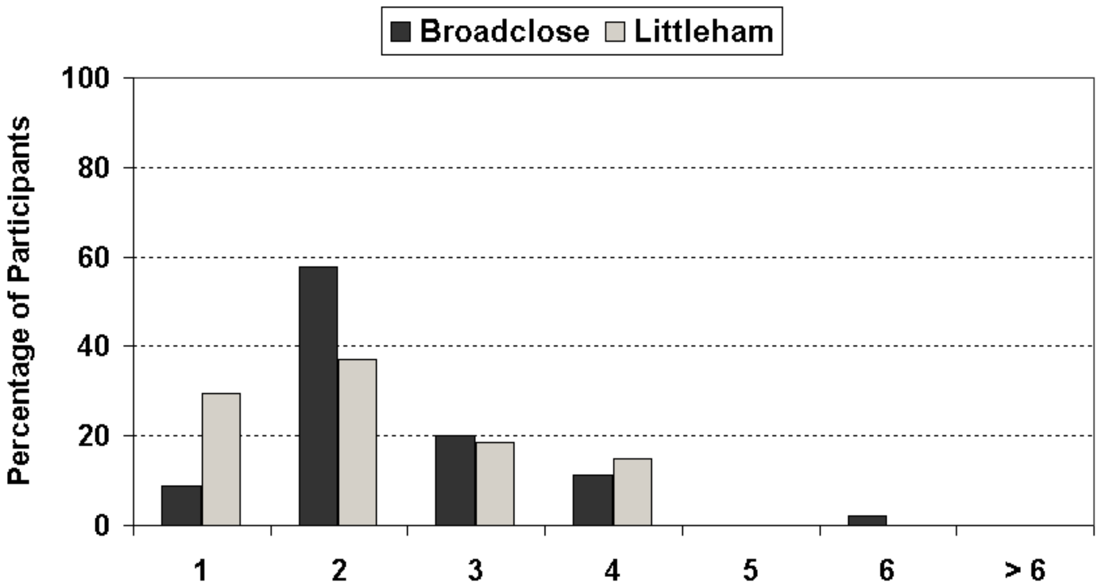


Figure 3.11 Number of occupants per household in residential locations

3.3.3 Experience with Water Saving Devices

Overall, the majority of participants had previously used one of the given devices (Figure 3.12), although some participants did not know whether they had used some of the devices, for example a shower restrictor. This is potentially attributable to the terminology used, as people may not necessarily know them as being called this. It may also arise from incidents where they know they have not used it within their home (or those of relatives), but are unsure as to their use of them in public bathing facilities (such as swimming baths) and therefore selected the 'Unsure' answer.

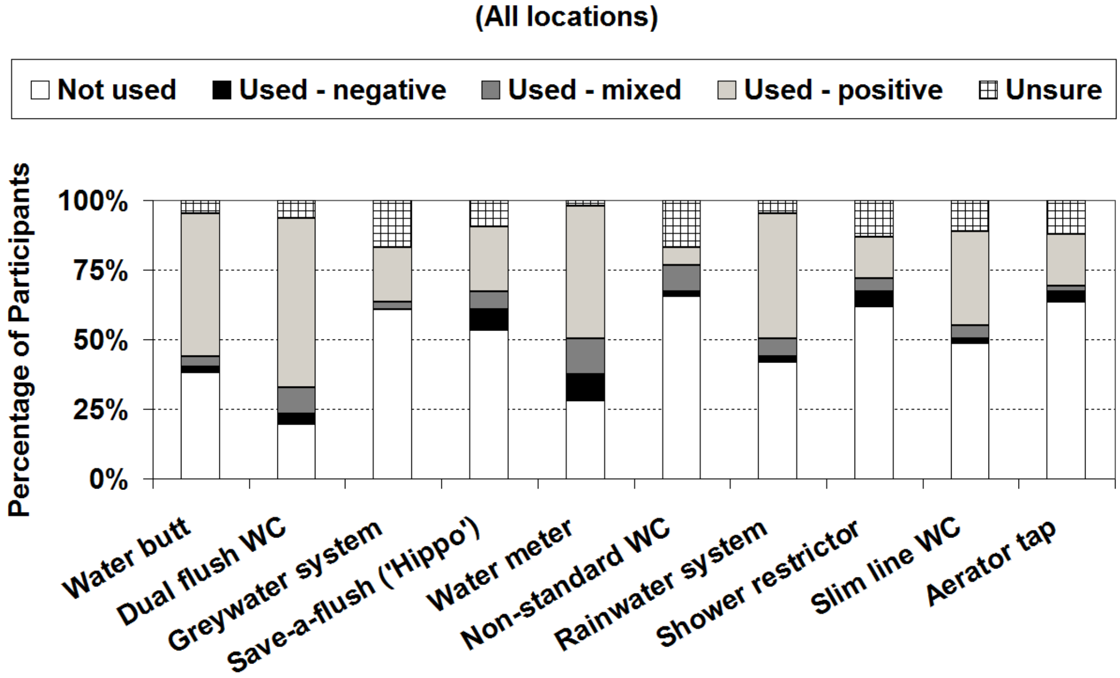


Figure 3.12 Participants experiences with water saving devices

In order to ascertain whether participants had awareness of or had experienced or used RWH, the question: 'Have you ever used a RWH system?' was asked, followed by a request for information on the location of the system (Figure 3.13) and space for the participant to give any other details they wanted. This question was not asked in questionnaires where locations had RWH systems (ICP2 and Broadclose), as obviously these participants are currently system users. 25% and 19% of ICP1 and Littleham participants, respectively, had used a RWH system with most having used them within a home environment, although some participants chose not to disclose where they had used one. Some participants expanded using the text box provided and details included: '*abroad: living in the Caribbean*'; '*worked at CAT in Wales*'; '*I have seen RWH in New Zealand and found it brilliant*' and '*parents have set up a water harvesting system at their house and also have several water tanks*'.

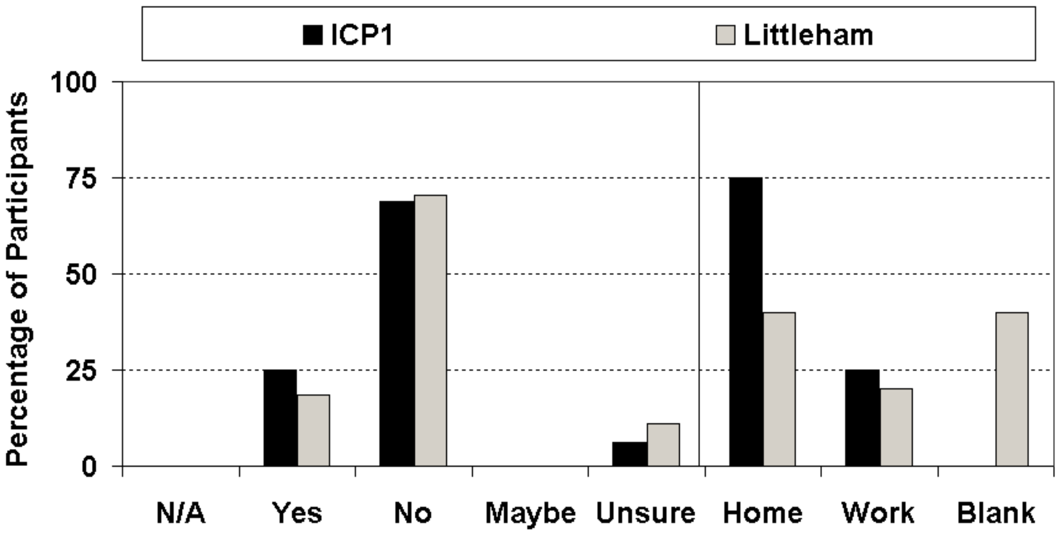


Figure 3.13 Exposure to using a RWH system

The previous assumption that participants in locations that had RWH would automatically respond that they had used a RWH system (hence why this question was not consistently applied across all locations), was proved erroneous. It was identified through the question on water saving devices, that participants in ICP2 did not necessarily know that they had used a system. This is illustrated in Figure 3.14, for the ICP2 location, where the percentage of participants who answered 'not used' was 53%; thus over half of the participants did not realise or had potentially not been informed that the building within which they worked had a RWH system.

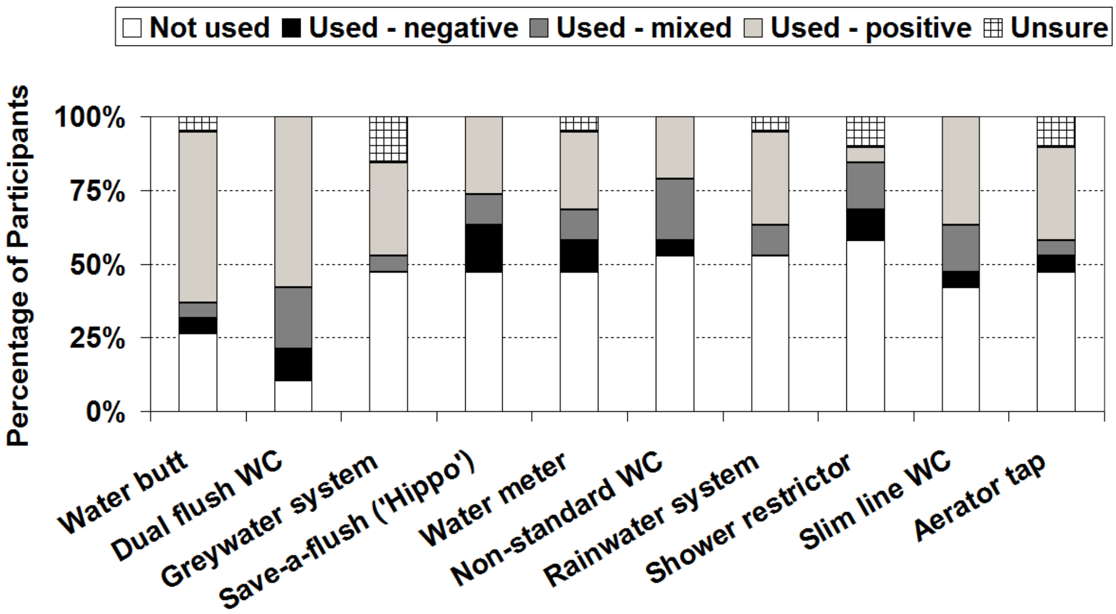


Figure 3.14 ICP2 experiences with water saving devices

This was not the same for Broadclose, but several comments were made highlighting that when participants first became residents in the development they too did not realise or were not informed/did not remember being informed (by whichever party) that their houses were fed by RWH. For example the following comments were given: '*didn't know it was installed when we moved in*'; '*did not know it was there until moved in*' and '*I didn't know it was there when moving in*'. This is perhaps not surprising, as in neither location are the participants directly responsible for operating or maintaining the RWH systems – such services are either provided by a building management team or a maintenance provider employed by a management company. They are paying for costs associated with operation and maintenance costs via a blanket service charge (which is included in rental payments for non-owned properties). The primary implication of this finding and of more concern to informers is that the profile of and public exposure to RWH is not being maintained or enhanced, as people are often not aware they have contact with a system. Despite this observation, 45% of all participants had used a RWH system and had a positive experience in doing so. Negative experiences were reported, but only in 2% of cases and mixed experiences constituted a low 7% (Figure 3.14).

3.3.4 Acceptability of Uses and Associated Risk

This section was concerned with ascertaining information on the sources of water and the types of reuse that would be acceptable to participants. Most systems available in the UK are promoted as being fed from roof-tops and suitable for WC flushing and garden use (though a system for both uses is rarely fitted), with some mentioning laundry use. In some instances increasing the range of catchment areas and end uses can be beneficial to the water saving efficiency and financial viability of a system; therefore it is particularly important to understand the sources and uses that would be acceptable.

To the question '*Which of the following sources would you consider using to flush a WC?*' 93% chose 'Yes' to rainwater from their roof, 76% to rainwater from neighbouring roofs and 64% to greywater from their house. Rainwater from surrounding roads/car parks and greywater from neighbouring houses received a more mixed response, with the most people being 'Unsure' about the latter (Figure 3.15). This indicates that, *in principle*, both individual and communal RWH systems would be widely accepted for WC flushing.

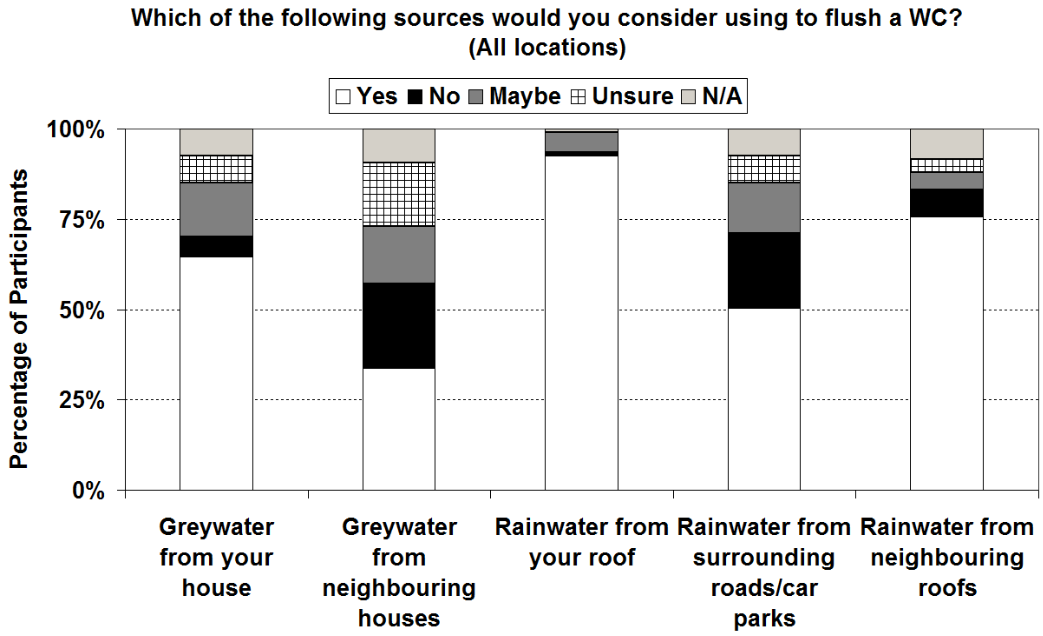


Figure 3.15 Acceptability of sources for reuse

In terms of the uses that people would be willing to consider RWH for, Figure 3.16 illustrates that the most widely accepted would be (in order of popularity) general outdoor use (92%), garden watering (89%), car washing (86%) and bathing animals (56%). Use for clothes washing (laundry) was less popular, with 38% of participants choosing 'Yes', 27% choosing 'No' and 23% choosing 'Maybe'. For other more 'personal' uses, such as personal washing, other potentially ingestible uses (such as washing vegetables) and drinking, the most popular answer was 'No' (38%, 57% and 62%, respectively).

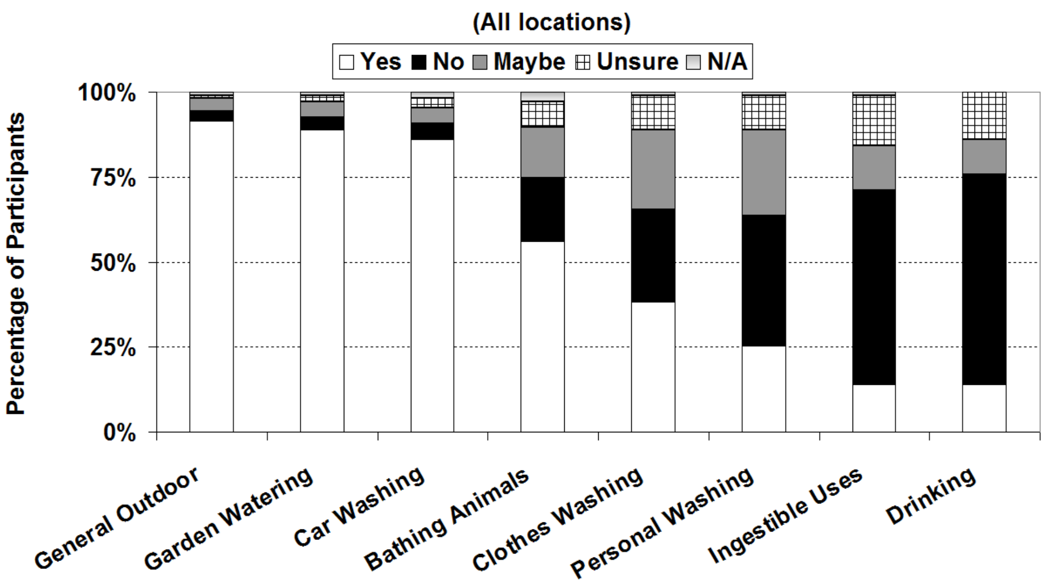


Figure 3.16 Uses for which participants would consider RWH

This is corroborated by responses to a subsequent question on 'risk' participants attributed to different uses. Similar to the result identified by Hurlimann (2007b), this study found that participants' perception of risk increased as the use became increasingly personal (Figure 3.17). The range of responses is shown in Figure 3.17 as a standard deviation bar, as the results are compiled for all participants across all the locations.

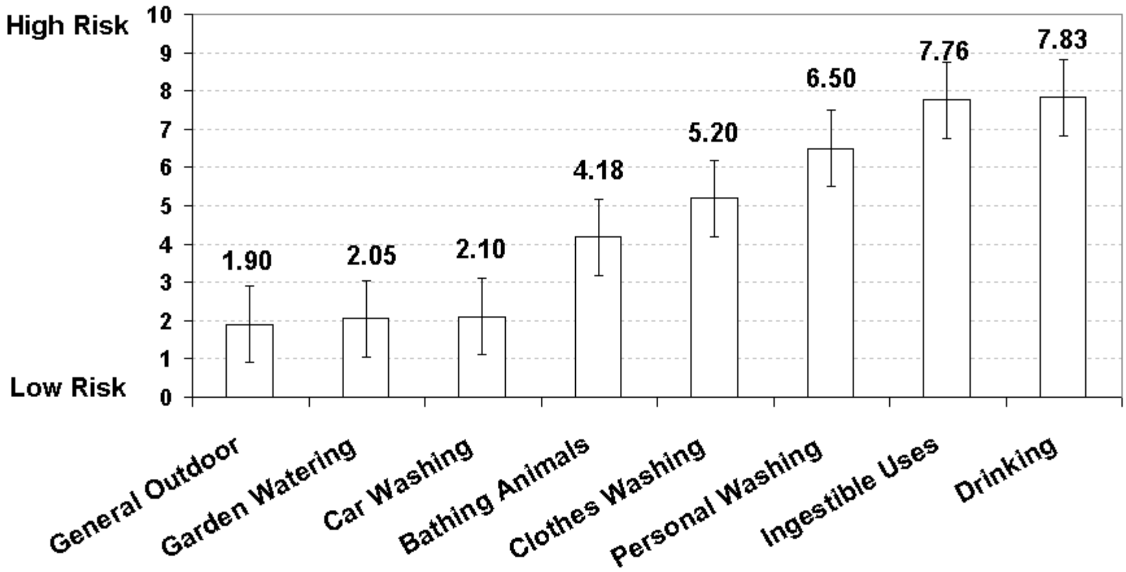


Figure 3.17 Average 'risk' associated with different RWH end uses

In terms of differences between RWH system users and non-users, Figure 3.18 illustrates there was very little difference between the risk ratings of the two groups. To confirm that there was no statistically significant difference between the ratings of the two groups the parametric T-test (t) was performed within SPSS. This was used rather than the non-parametric Mann-Whitney U-test, as examination of the descriptive statistics produced using the 'Explore' function showed that the data displayed a normal distribution. The tests for normality were not significant at the p = 0.05 significance level, which indicated a breach in the assumption of normality did not occur (Table 3.4).

Table 3.4 Results of tests for data normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Risk	User	.220	8	.200*	.863	8	.129
	Non-user	.228	8	.200*	.889	8	.229

A box plot (Figure 3.19) and the subsequent T-test (2–tailed) result confirmed that there was not a significant difference (at the p = 0.05 level) between the risk ratings of the users and non-users (t = -0.202, p = 0.843). Levene's Test for homogeneity of variance (F) showed that the variances of the two groups were equal i.e. that F was not significant at the p = 0.05 level (F = 0.201, P = 0.661) and therefore the t-value for equal variances was used.

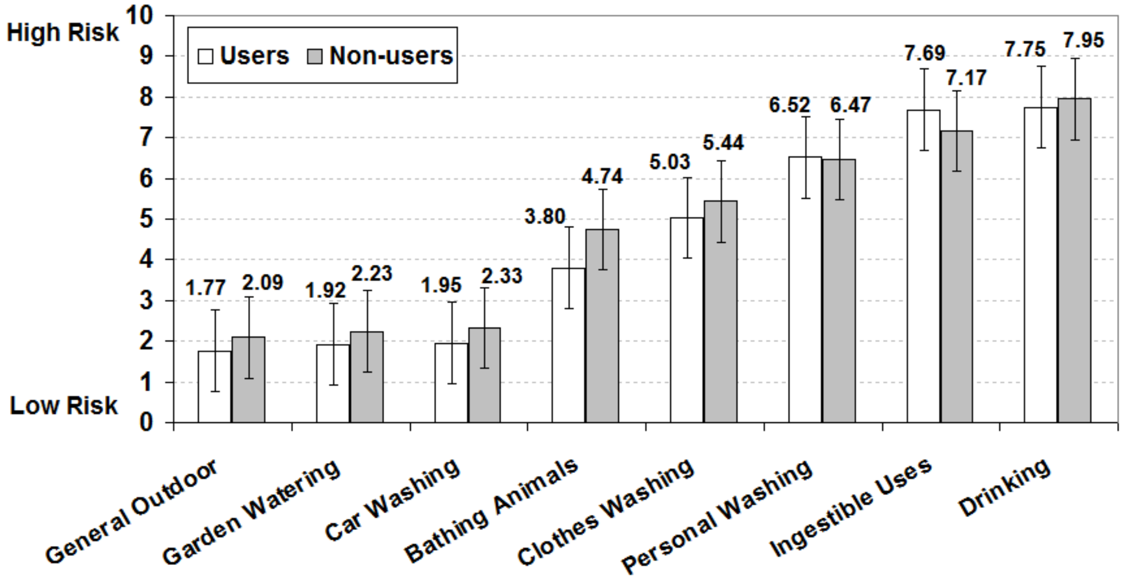


Figure 3.18 User and non-user average 'risk' associated with different RWH end uses

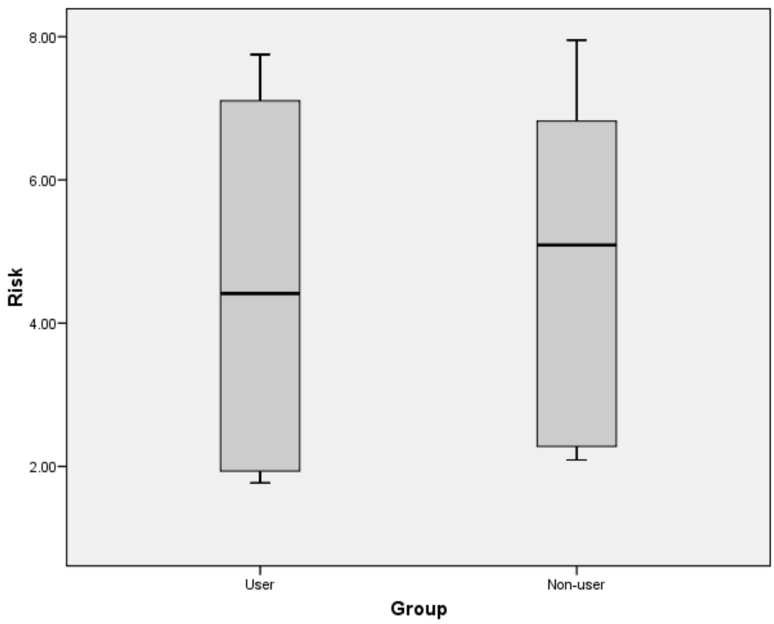


Figure 3.19 Plot comparing the range of risk ratings for RWH system users and non-users

These findings seem to reinforce that the uses for which RWH is currently being promoted are in line with their acceptability. However, greater consideration of installing systems that combine a range of uses (such as WC and outdoor usage) should perhaps be undertaken. Additionally, increasing the promotion of other more personal uses, such as clothes washing, might require more reassurance of the level of risk associated with such a use for some householders.

3.3.5 Current and Future Sources of Information

Participants were asked if they had ever obtained information on RWH and if they had to give further details. In all locations, over 65% of people had never obtained information about RWH (Figure 3.20). For the few that had obtained information, reasons and sources included:

- '*Investigated while drawing up plans for house renovation*';
- '*We looked for info on how it worked*';
- '*As part of house sales literature, basic info only was obtained*';
- '*Got a brochure from rainwater harvesting system manuf*';
- '*Via CAT in Wales for Eco Vegan Community that unfortunately didn't happen*';
- '*From water service provider when enquiring about rainwater harvesting*'.

Significantly, the majority of these activities were instigated by the participants themselves; in only one case was the information given to the participant by a third party without requesting it.

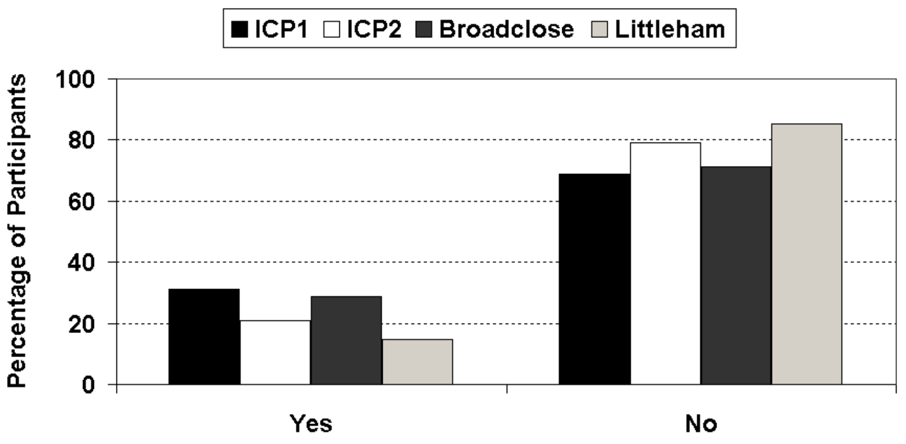


Figure 3.20 Have you ever obtained information on RWH?

Additionally, participants were asked if information on RWH systems was more widely available, how it would affect their consideration of installing such a system. 70% of all participants chose the 'encourage' option (Figure 3.21), highlighting that perhaps current information provision and promotion activities are not wide-ranging enough.

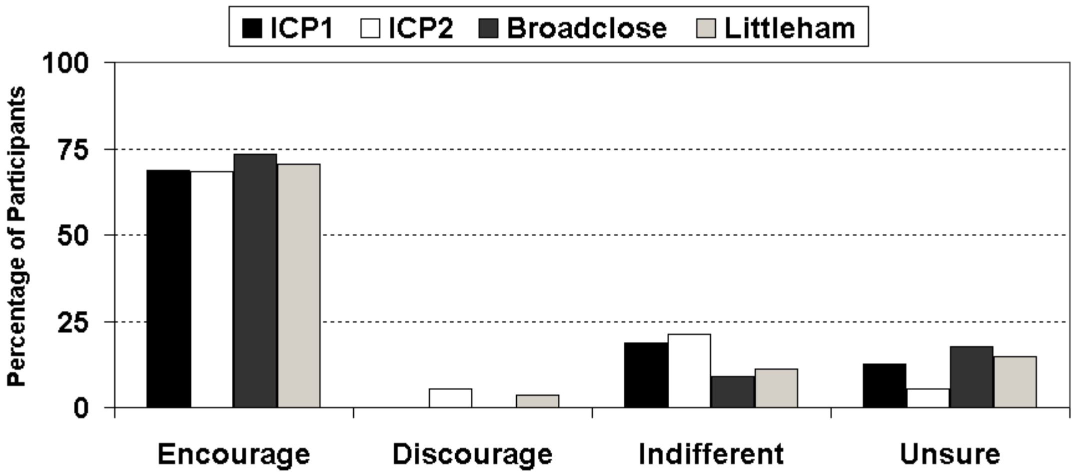


Figure 3.21 How would wider availability of information affect your consideration of installing a RWH system?

When asked where would be the best place from which to obtain information, the majority of participants chose the option 'With my water bill'. However, a high number also chose 'None of the above' and entered 'Internet', 'Web' or 'Online' in the 'Other' text box (Figure 3.22).

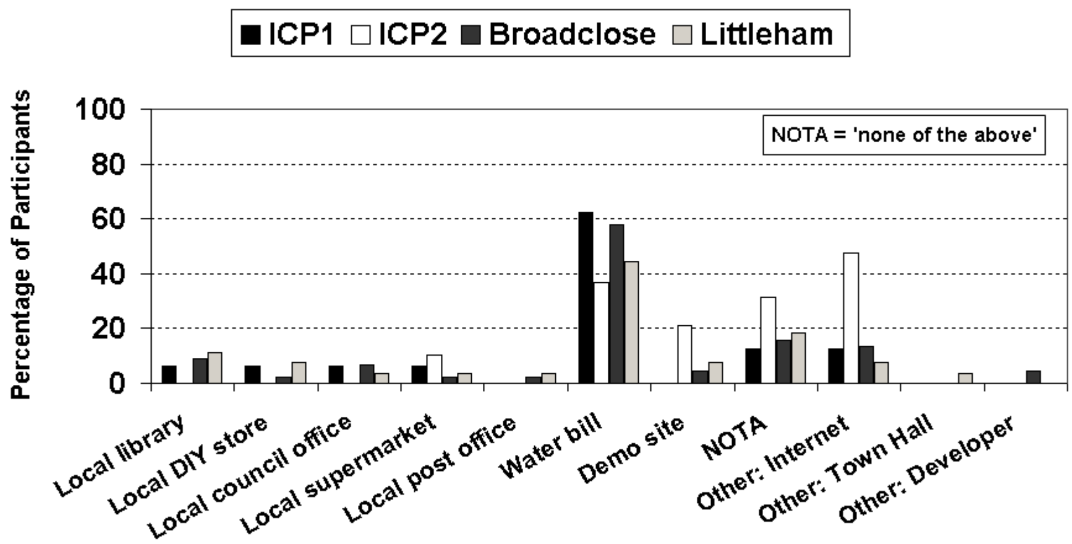


Figure 3.22 Where would be the best place to access information on RWH?

These results suggest that water service providers (WSPs) may need to promote measures beyond simple water saving devices and include information with water bills. Furthermore, the form this could take could be the address of an independent/government-endorsed website providing comprehensive information on RWH, as well as links to other suitable material. Such an information source would need to be well maintained and regularly updated as one participant complained that they had tried to obtain information but that "*the UKRHA [UK rainwater harvesting association] website is full of 'pages not found*". However, it should also be noted that this website was formed to serve as a focal point for organisations with *business interests* in the rainwater harvesting industry and therefore may not be the best independent source of information to widely promote. The Environment Agency (EA) website already has information and 'FAQs' on RWH and greywater reuse, although some of the more detailed information it provides is in the format of links to cumbersome and academic-style reports. Further consultation-based research into an appropriate 'central' information source may be required. This finding is inline with research carried out on water conservation for water company customers, which suggested there is a need for one organisation to coordinate messages to ensure '*a consistent and more effective approach*' (EA, 2009).

3.3.6 Factors Encouraging Consideration of Implementing RWH

Participants were asked to rate a number of factors on whether they would *encourage* or *discourage* their consideration of installing a RWH system (or if they were indifferent or unsure about them). The results for users and non-users are illustrated in Figure 3.23. It was decided not to segregate the responses by location in this instance, as initial viewing of charted data revealed very little inter-location variation. Table 3.5 summarises the factors that were given, along with their references on Figure 3.23. The references are non-consecutive as some factors were removed during the pilot study, based on participant feedback.

There were very few differences in responses between users and non-users for each factor. In general responses to those factors expected to encourage and those to discourage consideration were as anticipated. For example, having a regular maintenance commitment, having to pay for it and having disruption to the home or life during installation would most likely discourage consideration and these were highlighted as being the discouraging factors. For example, on average 52% of participants chose the option that maintenance would ‘discourage’ them from considering installing a system, with numbers for that option being higher from users than non-users. A further observation was made on examination of the text boxes provided for participants to make additional comments. Three participants commented that the section on maintenance was not relevant to them, more specifically ‘*I have no opinion at all*’ or ‘*I cannot answer*’. These participants did not feel they had opinions on maintenance issues or that they could not give ‘correct’ answers rather than their perceptions or opinions. A small percentage of participants responded that promotion by various organisations would actually discourage their consideration, but the majority responded with encourage. A larger number of participants were indifferent to a large number of the factors, but again the majority either responded with encourage or discourage, depending on which factor was under examination.

Table 3.5 Factors and references for Figure 3.23

Factor	Factor Reference
Reducing high quality tap water for non-drinking purposes	F_1
Wider availability of information about RWH systems	F_2
Installation grants/subsidies	F_3
Saving money on water bills	F_4
Confidence in those installing it	F_6
Helping the environment	F_7
Helping to reduce urban flooding	F_8
A regular maintenance commitment	F_11
Promotion of systems by water companies	F_12
Promotion of systems by local or national government	F_13
Promotion of systems by environmental groups	F_15
My neighbour/someone in my street got one	F_16
Unrestricted water use	F_17
A relative or close friend got one	F_21
Having to pay for regular maintenance	F_22
Having disruption to my home/life during installation	F_25
Seeing a RWH system in action	F_26

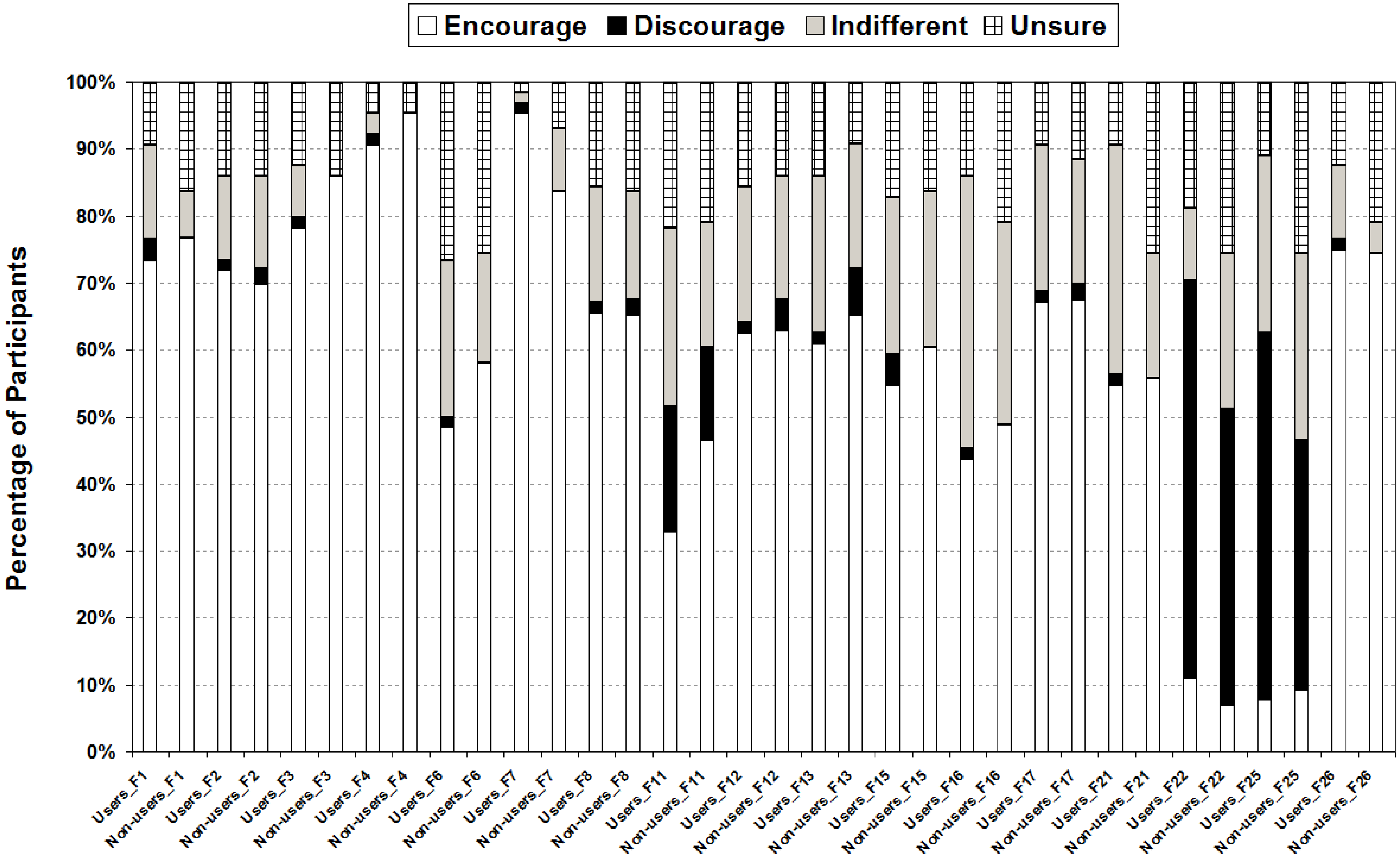


Figure 3.23 RWH system user and non-user responses to factors encouraging consideration of RWH (see Table 3.5 for legend)

It is possible that the responses to some factors in this section may be subject to a degree of social desirability bias (Oppenheim, 2005). This is the tendency of the participant to respond with answers that are viewed as more socially acceptable, or favourable, than others. For example, even though a participant may not really be encouraged by the promotion of RWH by local or national government, they may still be inclined to use the ‘encourage’ response as, in their mind, it complies with the answer the researcher ‘wants’ and presents the participant in a more positive (or compliant) light.

One way of accounting for social desirability bias is the implementation of an appropriate scale. The Marlowe-Crowne Social Desirability Scale (MCSDS) is perhaps the most well-known. However, due to its length (33 individual questions), it is regarded as cumbersome and likely to induce participant fatigue when used in association with the questionnaire at the focus of the research (Thompson and Phua, 2005). Similar is true of the Paulhus’ alternative scale. Short-forms, such as the Strahan-Gerbasi X1 and X2, have been cited in numerous studies (Thompson and Phua, 2005). Items on these scales include statements requiring true or false responses, such as: ‘you are likely to gossip at times’ or ‘you never resent being asked to return a favour’ (Thompson and Phua, 2005). A weakness of these scales is that individuals do differ in the degree to which they act in a socially desirable way and thus measures can confound genuine differences with social-desirability bias. Additionally, the context of the wording on the Strahan-Gerbasi short-form scales is not particularly well suited to integration within questionnaires that seek to elicit information on an individual’s environmental or sustainability attitudes or behaviour. For example, if a participant has just answered three questions about their water-using (or recycling) behaviour, a question about how much they gossip is likely to confuse or annoy them.

Gilg and Barr (2006) conducted a survey relating to environmental behaviour, including efficient water use. The study controlled for social desirability using questions such as: ‘most of my neighbours and friends are environmentally friendly’ and ‘most people I know don’t do much to help the environment’. It was identified that those classified as committed and mainstream environmentalists claimed their neighbours and friends helped the environment. The converse was true of those classified as non-environmentalists. Furthermore, non-environmentalists were less likely to know someone who was environmentally friendly – this was taken to indicate that non-environmentalists were less likely to believe that such behaviour was socially desirable. These findings were used as the basis for determining the social desirability of the responses of the participants in the present study. At the beginning of the questionnaire two questions were asked on the participants' environmental inclination:

> Q1) Do you consider yourself to be environmentally conscious?
> Q2) Do you value water conservation?

Figure 3.24 illustrates the responses to these questions. It would appear that since the study by Gilg and Barr (2006), environmentally friendly behaviour (or at least appearing to be) has become more socially acceptable – or that householders have genuinely become more aware of environmental issues. The lack of differentiation between environmentally inclined participants prevent further interrogation of the social desirability of the encourage/discourage question results. It is acknowledged that the response set used (Yes, No, Maybe, Unsure) was perhaps not the most appropriate and the more traditional Likert scale of 'Strongly disagree', 'disagree', 'neutral', 'agree' and 'strongly agree' should perhaps have been utilised. This may have led to stronger differentiation between groupings. Additionally, two further questions inquiring about neighbours' and friends' environmental behaviour should perhaps have been included. These were not originally included as it was thought the number of questions was already quite daunting, despite having been reduced from the pilot study. The author duly acknowledges the limitations placed on interpreting the data by omitting these. However, the author suggests that further research into the development of an environmentally-orientated short-form social desirability scale may be required.

In order to determine which of the previously presented factors would be *most* likely to encourage participants to consider installing RWH, they were presented with a refined predetermined list from which they could only select one factor (Figure 3.25). Participants were given the option to include other factors not covered by the response set, to prevent participants feeling forced into choosing one. No additional factors were added, despite a very small number of participants choosing the 'none of these' option. Across the four locations an average of 40% of participants chose the option 'installation grants/subsidies' and 29% 'saving money on water bills'. Table 3.6 summarises the rank of each factor for each location, overall and for users and non-users (based on the number of responses it received). Where a factor received the same number of responses, joint rankings are assigned and highlighted using an asterisk.

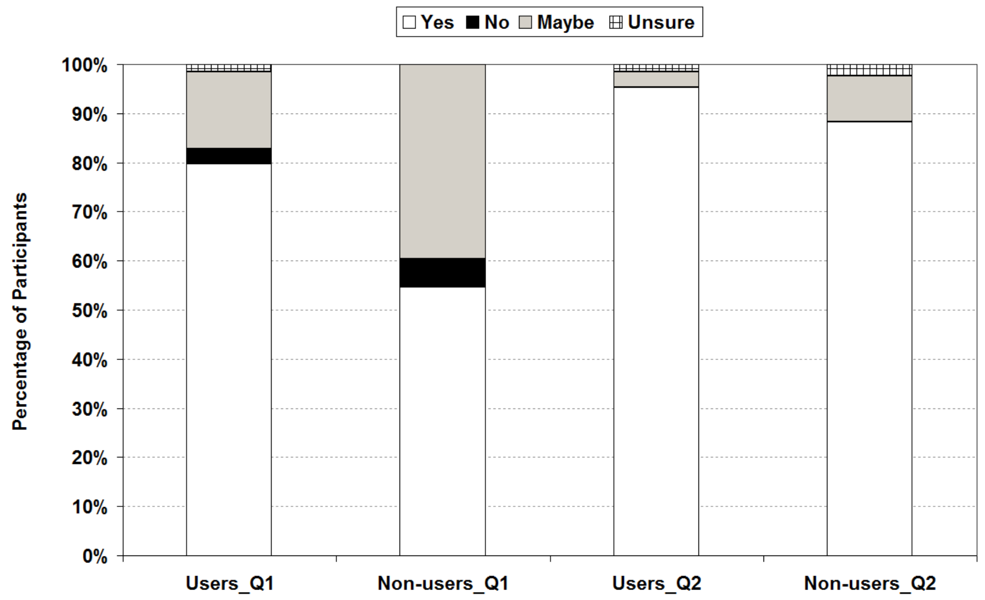


Figure 3.24 Participant claims regarding environment and water conservation

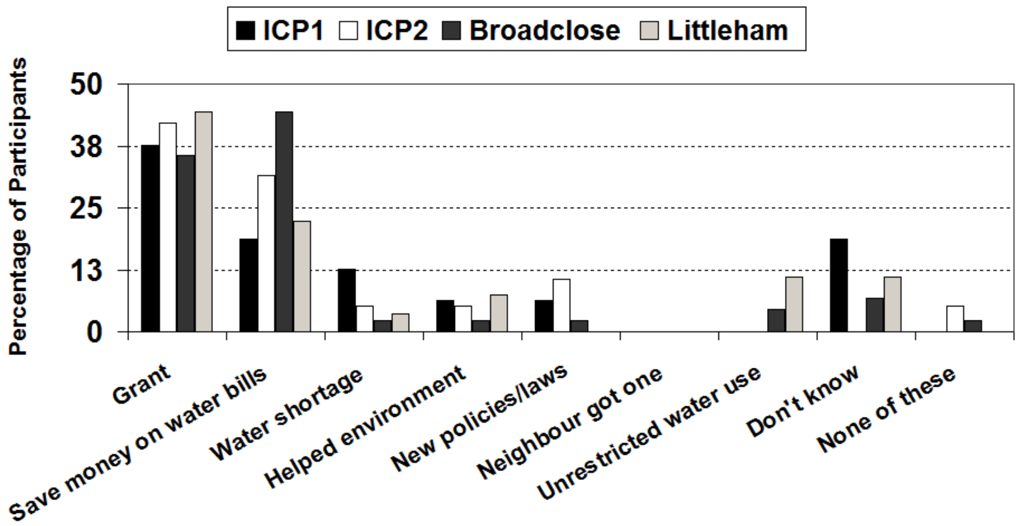


Figure 3.25 Factors encouraging consideration of installing RWH

Overall the factor with the highest ranking was the provision of a grant, which was followed by saving money on water bills. These factors were either ranked first or second at all the locations. Rankings for the remaining factors were different across the locations; although the third most common answer overall was 'Don't know'. This indicates many participants were unsure as to what would encourage their consideration of installing a RWH. Overall, experiencing a water shortage ranked fourth, followed by helping the environment in fifth and new policies/laws in sixth. There was no difference between users and non-users for the first and second ranked factors, which again were provision of a grant and saving money on water bills. Interestingly, a number of users qualified their 'saving money on water bills' response with comments to the effect that they did not feel they were saving as much as they should have been. For users the third highest ranked factor was new policies or laws and for non-users was 'Don't know'. For users the 'Don't know' response ranked fourth. Again this reinforces that there is an uncertainty about which, beyond financial incentives, factors would encourage UK householders to consider installing RWH. This indicated the majority of the theorised responses did not adequately represent the factors of importance in facilitating household consideration of RWH and would need reviewing if used in future research. It was deemed that performing statistical analyses would be inappropriate. Performing such analyses might produce misleading results placing emphasis on factors that were in fact not particularly significant for participants.

Table 3.6 Factors encouraging RWH ranked by number of responses received

	ICP1	ICP2	BC	LH	Overall	Users	Non-users
Grant	1st	1st	2nd	1st	1st	1st	1st
Save money on water bills	*2nd	2nd	1st	2nd	2nd	2nd	2nd
Water shortage	3rd	*4th	*5th	5th	4th	*4th	4th
Helping the environment	4th	*4th	*5th	4th	5th	*4th	5th
New policies/laws	4th	3rd	*5th	\	6th	3rd	7th
Neighbour got one	\	\	\	\	\	\	\
Unrestricted water use	\	\	4th	*3rd	\	5th	6th
Don't know	*2nd	\	3rd	*3rd	3rd	*4th	3rd
None of these		*4th	*5th	\	7th	*4th	\

These results highlight that monetary concerns are a primary factor affecting householders' consideration of installing RWH systems, echoing findings in Parsons *et al.* (2010) and White (2009). Currently only businesses are eligible to claim financial benefits when fitting RWH systems, under the Water Technology List and Enhanced Capital Allowance (ECA) schemes (DEFRA and HMRC, 2007). After the survey was undertaken, several WSPs (including the WSP for the study area, South West Water) revised their waste water and surface water drainage charging structures (South West Water, 2009). These permit properties that are not connected to a sewer to claim a reduction in these charges. From the post-questionnaire interviews conducted (Section 3.3.10) it was identified that participants had not been informed of these changes (by any organisation) or that the changes could help increase savings on their water bills. This could be due WSPs being concerned regarding surface water drainage income, but full investigation of such reasons would be required to comment further.

3.3.7 Maintenance Issues

Participants were asked: ‘Do you think RWH is a good thing?’ This question was also repeated at the end of the questionnaire, to identify whether the questionnaire had an impact on participant opinion and a change was made. At both the beginning and end of the questionnaire, the majority of participants thought that ‘Yes’, RWH is a good thing (Figure 3.26). Total percentages overall changed, though were not significantly different (at the $p = 0.05$ level: paired-sample T-test, $t = -0.600$, $p = 0.591$, two-tailed), between the beginning and end by 3% from 92% to 89%, respectively. From this it could be implied that receptivity to awareness raising and knowledge transfer activities would be positive if conducted in an appropriate manner and adequately supported by further research into how to increase receptivity.

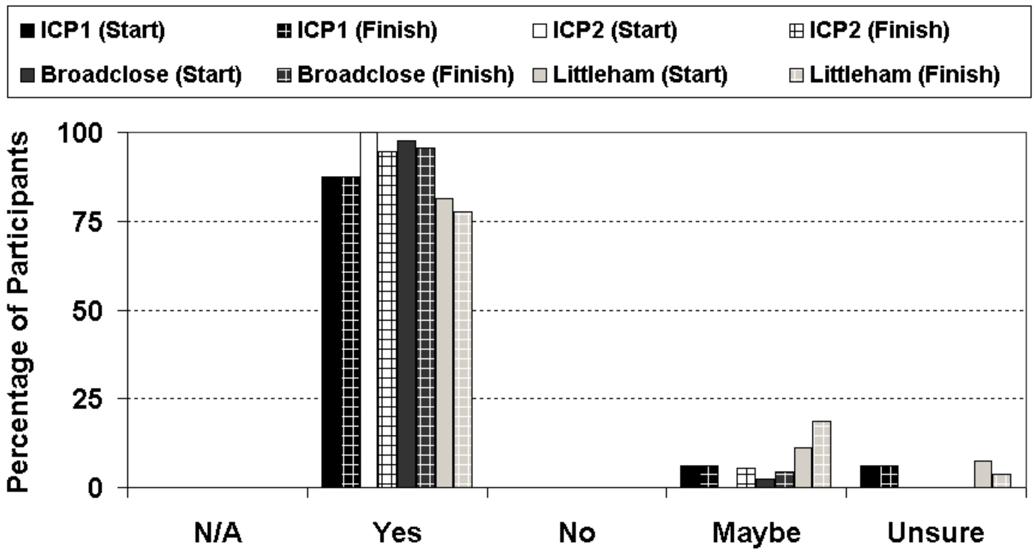


Figure 3.26 Do you think RWH is a good thing?

RWH is not a ‘fit and forget’ technology and one area in particular where there has been limited quantification of the awareness of and knowledge is maintenance activities and associated costs. Often it is not until a system has been installed that building owners become aware of maintenance commitments. Participants were asked 'Do you think it is important to perform routine maintenance of a rainwater harvesting system?' An average of 81% of participants chose 'Yes' (Figure 3.27).

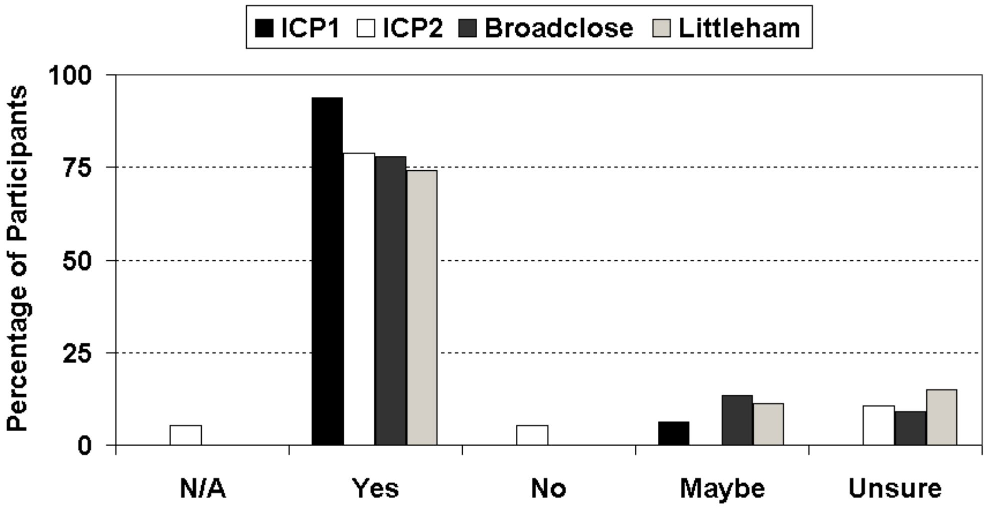


Figure 3.27 Participants' consideration of the importance of maintenance

Despite this recognition, responses to subsequent questions identified that the level of knowledge regarding the types of maintenance activity that required undertaking, the function the activities served or the frequency with which they needed to be undertaken was variable. This is exemplified by the spread of responses (including a large proportion of 'Don't knows') in Figure 3.28, regarding a question on maintenance activity frequency.

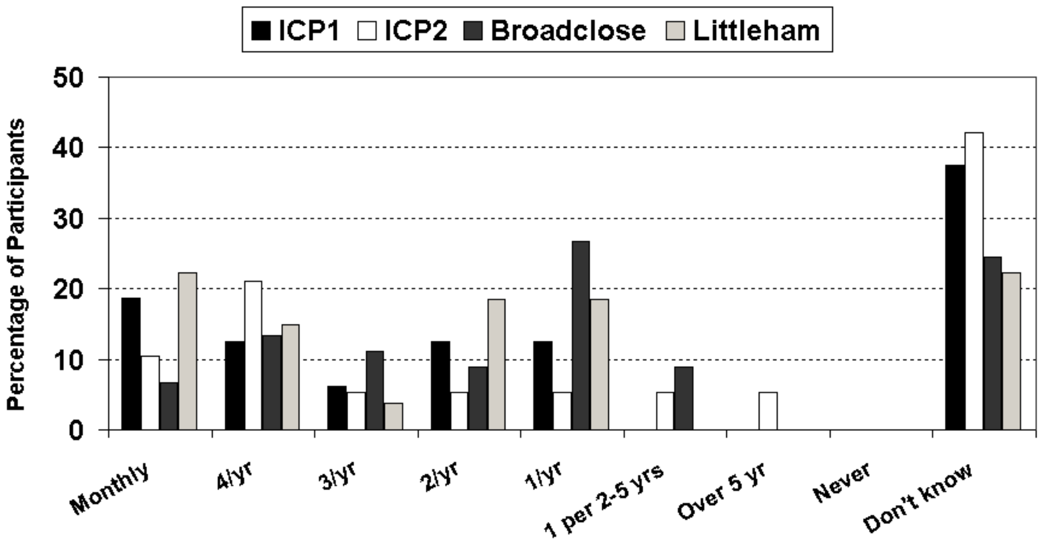


Figure 3.28 Perceived frequency for conducting RWH maintenance activities

The recent British Standard for RWH systems (BSI, 2009) recommends the frequencies summarised in Table 3.7, for a number of components.

Table 3.7 Recommended frequency of maintenance activities (BSI, 2009)

Component	Frequency	Component	Frequency
Rainwater goods	Annually	Water level gauge	Annually
Filter	Annually	Wiring	Annually
Storage tank	Annually	Pipework	Annually
Pump/pump control	Annually	Markings	Annually
Back-up supply	Annually	Support and fixings	Annually
Control unit	Annually	UV lamps	Every 6 months

However, the standard was not introduced until after the present survey was completed, therefore research by Roebuck (2008) was used to determine the response set for the frequency of recommended activities for inclusion in the questionnaire. Additionally the recommended frequency was taken to be three times per year for cleaning the catchment (roof) and filters, replacing a UV lamp (where present) and checking the pump.

Even at locations with RWH, users were divided in their responses (Figure 3.29). From Figure 3.29 it appeared that there was not a significant difference between the responses of users and non-users. This was confirmed at the $p = 0.05$ level with the use of an independent T-test (with equal variances, $F = 0.361$, $p = 0.556$), where $t = 0.939$ and $p = 0.362$ (2-tailed). This is perhaps not surprising as in locations with RWH, such services are either provided by a building management team or a maintenance provider employed by a management company. However, a subsequent question to users on who they thought undertook maintenance activities revealed that they may not have found out/been informed about such matters (Figure 3.30). Very few knew who was responsible for maintenance as the majority, (>50%) in both cases, responded with they didn't know. For both locations it was a RWH/maintenance company.

It terms of recommended frequencies, less than 10% of both users and non-users chose the three times per year response and 20% or less chose the once per year response. Overall 30% of users and 28% of non-users responded with they did not know. Despite the recommendations, the frequency with which maintenance activities will be required is subject to a range of factors, such as local weather, proximity of trees and, in specific relation to the catchment area, the type of material and its slope. Therefore participants were also asked to rate how important they thought cleaning the catchment area was, in terms of both system function (SF) and water quality (WQ), which arguably requires high level thinking about system technical aspects. This RWH system component was chosen, as it is the most visible part of any type of system and can have the largest impact on both factors (BSI, 2009). As can be seen from Figure 3.31, there was a high variability in responses. Users rated it as equally important to system function and water quality, with the majority rating it with a 1 or 3. Non-users showed a higher degree of variation between its importance for system function and water quality, with the latter being seen as slightly less important.

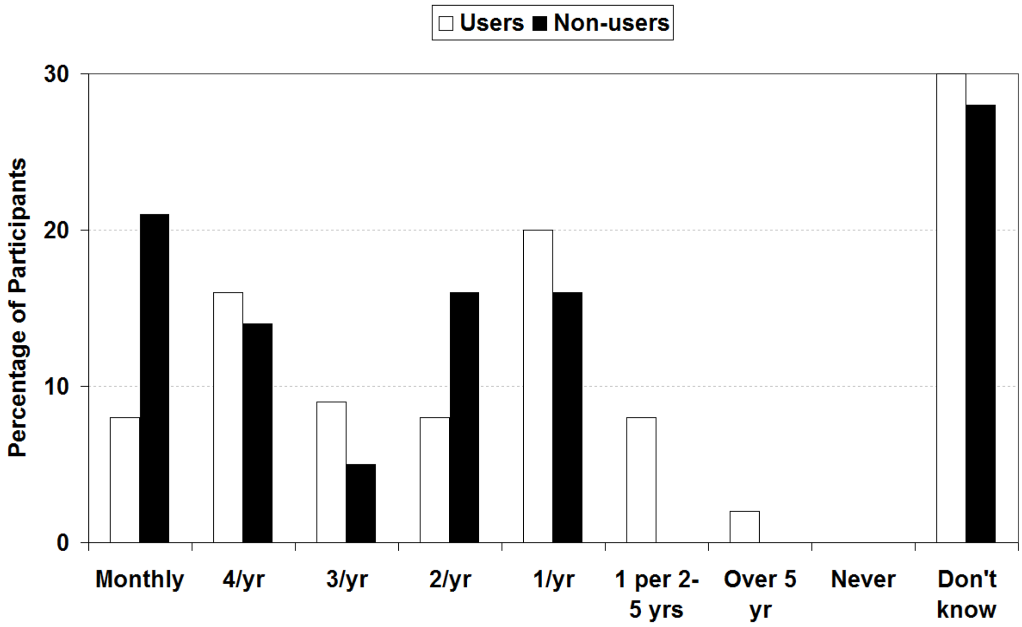


Figure 3.29 Perceived frequency for conducting RWH maintenance activities

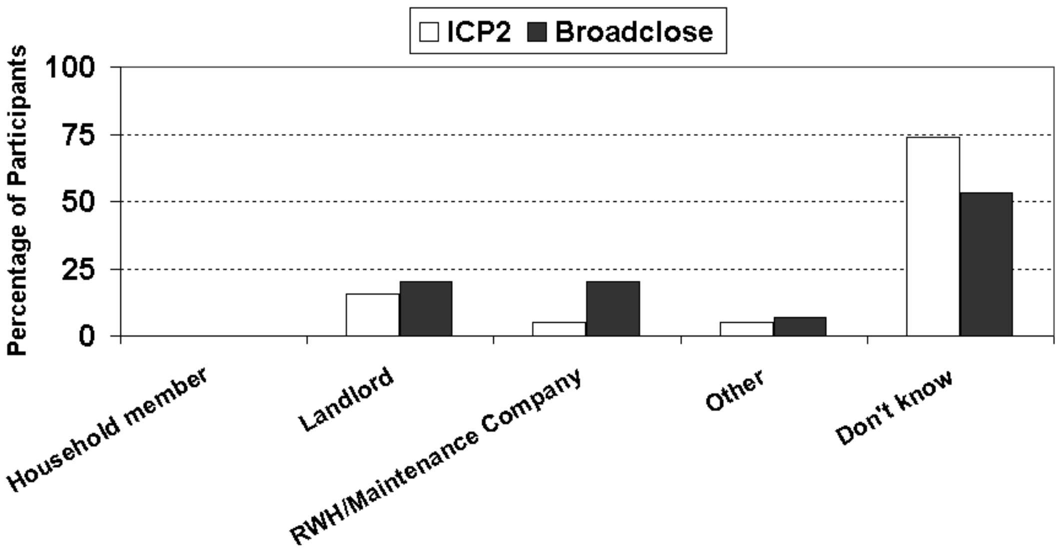


Figure 3.30 RWH system users' knowledge of maintenance provision

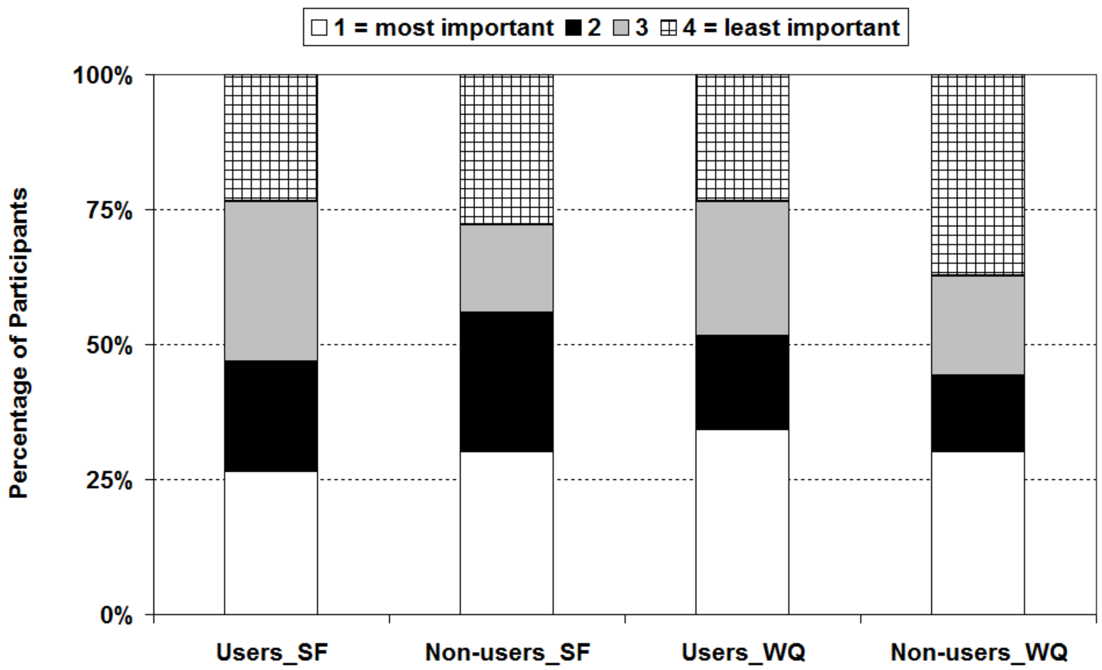


Figure 3.31 Participant ranks of the importance of cleaning the RWH catchment for system function (SF) and water quality (WQ)

In terms of the cost associated with the previously mentioned maintenance activities, participants were as equally divided in their responses (Figure 3.32). Maintenance costs were generally perceived to be under £200 per year and the majority of participants would be willing to pay £100 or less. The actual cost for an average domestic property would typically be between £140 and £240 per year, or £250 for an annual contract with a maintenance provider (Roebuck, 2008). An independent T-test (p = 0.05) determined that there was not a significant difference between users and non users either for their estimated cost or willingness to pay responses (Table 3.8).

Table 3.8 T-test results for participant responses regarding RWH maintenance costs

Cost	F*	p*	t*	p*	Significant
Estimated	0.297	0.598	1.075	0.308	No
Willing	0.404	0.539	0.434	0.674	No

*F = the Levene Test statistic; p = significance level; t = the Student's T-test statistic

Univariate ANOVA (Analysis of variance) revealed there were no significant differences between the response chosen for the estimated and willingness costs for users (Appendix B). However, for non-users there were significant differences between the response chosen for the estimated and willingness costs, which are summarised in Table 3.9 (full results in Appendix B). This is identified visually in Figure 3.32, where it can be seen that the cost bands in excess of £300 are not present within the responses for the non-users willingness cost.

Table 3.9 Univariate ANOVA results for non-user responses regarding RWH maintenance costs

Cost band	Mean difference	Tukey HSD (significance	Significant
<£100 and £300-£400	22.500	0.019	Yes
<£100 and £400-£500	21.000	0.026	Yes
<£100 and >£500	20.500	0.029	Yes

This indicates a dissonance between non-users' estimated and willingness costs i.e. they are willing to pay less than they estimate the maintenance cost will be. Thus the results appear to indicate that perceptions of maintenance costs are, in this particular study, generally aligned with the lower end of the scale of actual costs. These findings highlight that perceptions of and willingness to pay for maintenance activities is highly variable, even where experience with a RWH has been had.

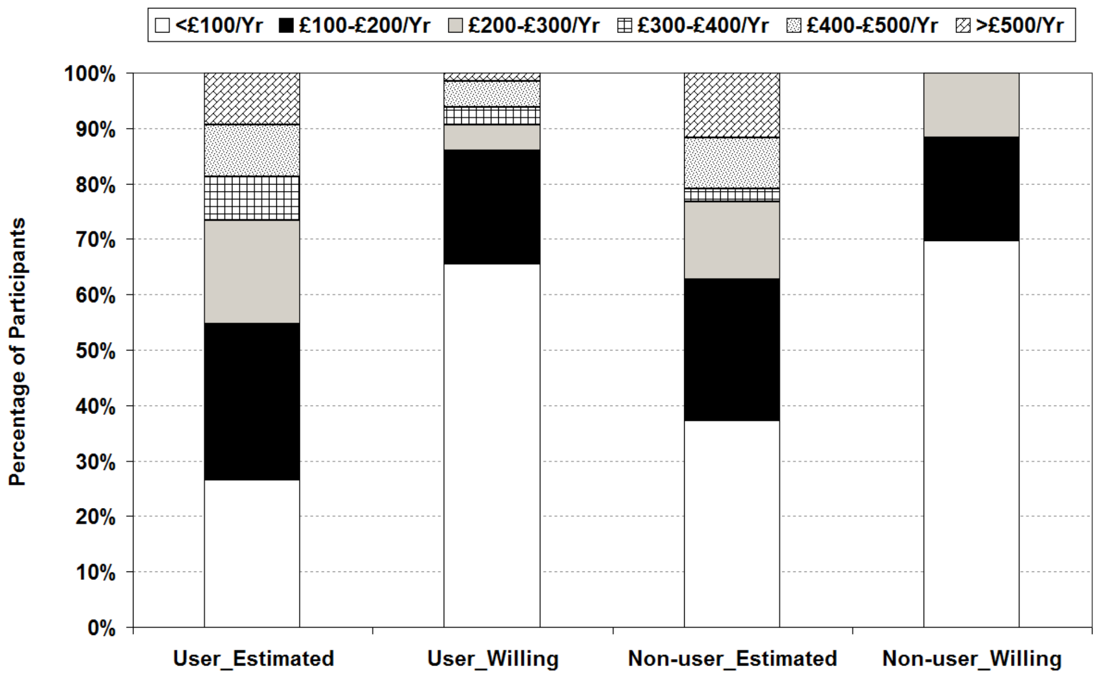


Figure 3.32 Perceptions of maintenance activity costs between users and non-users

3.3.8 Perceived Benefits of RWH

Participants were also asked about the benefits they thought RWH might present. Table 3.10 summarises the benefits that were suggested and their references for the Figures that follow.

Table 3.10 Benefits of RWH suggested to participants and their references on Figure 3.33 and Figure 3.34

Benefit	Reference
Helps me to feel I'm 'doing my bit for the environment'	_Altruism
Helps the environment	_Env
Saves valuable highly treated mains water from being flushed down the toilet	_WC
Saves money on water bills	_Money
Helps reduce local flooding	_Flood

As can be seen from Figure 3.33, the majority of participants (whether users or non-users) responded with 'Yes' to most of the benefits. By performing an independent T-test ($p = 0.05$) for between group effects (an ANOVA was not suitable as there were less than three groups) it was determined that there was not a significant difference between the number of responses (unequal variances, $F = 5.238$, $p = 0.028$; $t = 0.686$, $p = 0.498$) or for the type of response chosen (equal variances, $F = 0.197$, $p = 0.660$; $t = 0.433$, $p = 0.668$) for users and non-users.

Subsequently a one-way ANOVA with the Tukey HSD (honestly significant difference) post-hoc test was selected to permit a full within group comparison of the response set type (as the response set had more than three groups, the ANOVA was appropriate in this case). It was determined that there was a significant difference between the 'Yes' response and all the other responses (at the $p = 0.000$ level – see Appendix B for full post-hoc test results). Therefore for both users and non-users, the majority of participants responded with 'Yes'. However, this question is potentially open to a high degree of social desirability bias and therefore the results should be treated with caution. The author acknowledges that greater consideration to this should have been included in the design of this question/response set.

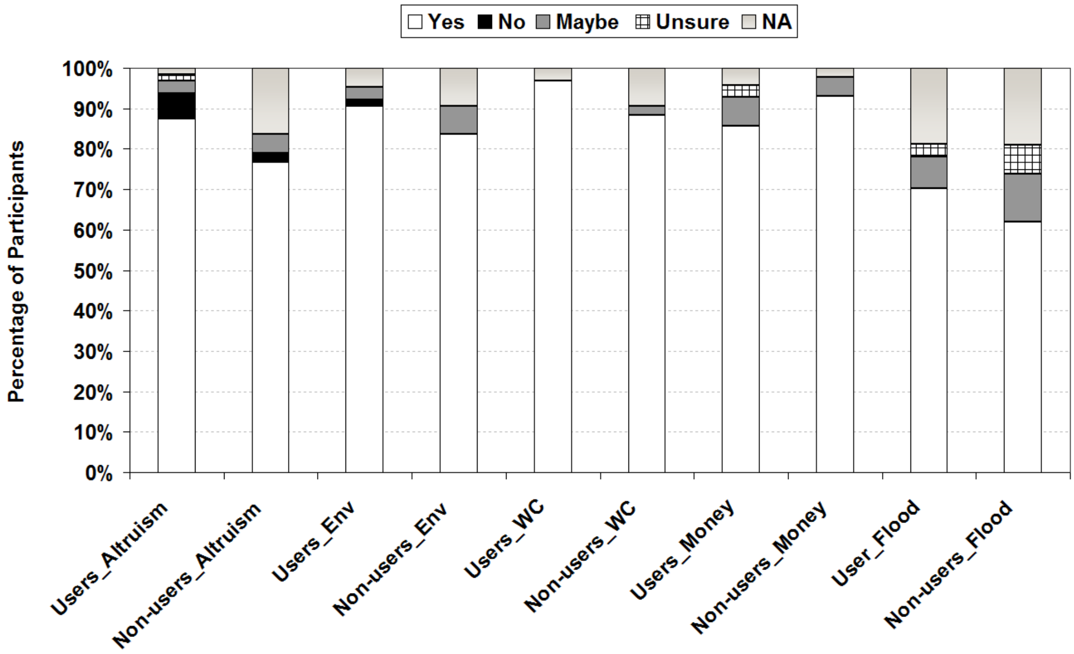


Figure 3.33 Participants' perceptions of the benefits of RWH (users and non-users)

In contrast, when the responses were examined location by location, there appeared to be some differences between the responses of participants (Figure 3.34). Perhaps most notable is that participants from LH appeared more likely to choose the 'NA' (i.e. not applicable) response than participants from other locations. This appeared to be most distinct for the 'Helps me to feel I'm 'doing my bit for the environment'' and 'Helps reduce local flooding' benefits. This may indicate that participants at this location did not relate to these factors, perhaps due to social or educational status (but this is not examined here). To determine the significance of the apparent difference a univariate ANOVA with Tukey post-hoc tests was performed, as there were both greater than three locations and possible responses. It was determined that there was a significant difference between the 'Yes' response and all the other responses across the locations (at the $p = 0.000$ level – Table 3.11). It was also confirmed that the responses between the different locations were significantly different (at the $p = 0.05$ level; $p = 0.000$).

Table 3.11 Univariate ANOVA results for the effect of location on response chosen to a question on the benefits of RWH

Locations with a difference in response	Mean difference	Tukey HSD (significance)
ICP1 and BC	-7.4583	0.000
ICP1 and LH	-6.7333	0.000
ICP2 and BC	-6.9821	0.000
ICP2 and LH	-6.2571	0.000

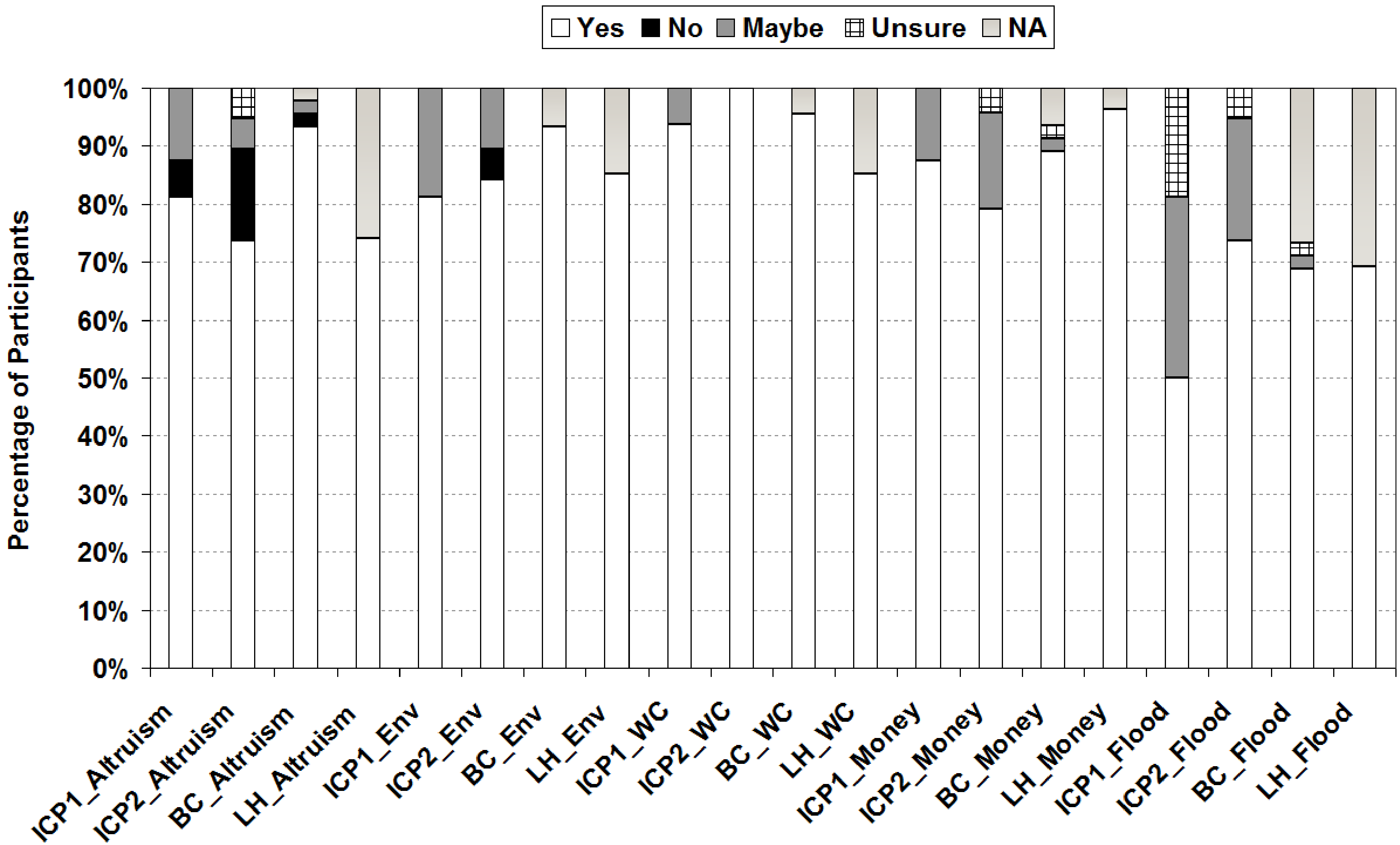


Figure 3.34 Participants' perceptions of the benefits of RWH (different locations), (see Table 3.10 for legend)

A further one-way ANOVA revealed significant differences between the ‘NA’ and ‘Maybe’ responses at the p = 0.05 level (Tukey HSD = 1.66667, p = 0.001). It was identified that there were significant differences between ICP1 and ICP2 compared to BC and LH for these answers – with ICP1 and ICP2 more likely to respond with ‘Maybe’ and BC and LC with ‘NA’. A possible explanation is that the minority of participants in residential locations did not have an opinion on a particular benefit.

3.3.9 Experiences with WCs flushed by RWH

Participants at locations with RWH systems were asked questions on the performance of the WC being flushed by water provided by the system. As illustrated by Figure 3.35, in both locations over 70% of participants noticed no difference in comparison to a WC flushed using mains water. Additionally, participants were asked to rate the same parameters on a scale of ‘good’, ‘adequate’ and ‘poor’ (Table 3.12). High numbers of participants in both locations rated the parameters ‘good’ (an average of 72% for ICP2 and 60% for Broadclose) and low numbers rated the parameters ‘poor’ (an average of 8% and 6%, respectively). However, there were slight differences between the locations for the ‘adequate’ rating, with Broadclose participants choosing this rating in 34% of cases, compared to 20% for ICP2. Despite a higher number of Broadclose participants rating the WC as ‘adequate’, a follow-up question revealed that overall all participants were either ‘very satisfied’ or ‘satisfied’ with the WC being flushed by RWH (Figure 3.36) and either ‘pleased’ or ‘not bothered’ about any differences they had noticed, although a fairly high number also chose the ‘N/A’ option (Figure 3.37).

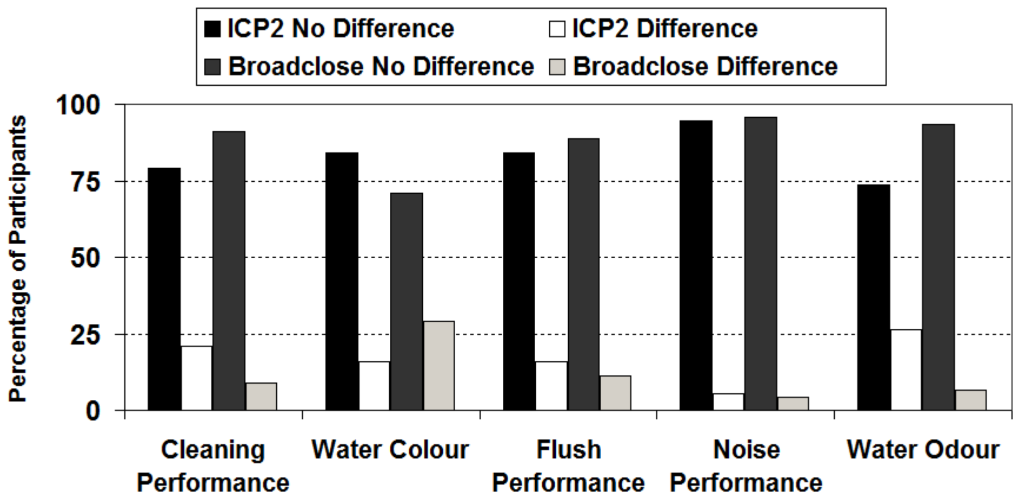


Figure 3.35 Differences in WC performance and aesthetics observed by participants

Table 3.12 Participants rating of WC performance and aesthetics (%)

	Good		Adequate		Poor	
	ICP2	**Broadclose**	**ICP2**	**Broadclose**	**ICP2**	**Broadclose**
Cleaning Performance	68	53	11	42	21	4
Water Colour	74	49	26	36	0	16
Flush Performance	63	62	37	33	0	4
Noise Performance	84	76	16	22	0	2
Water Odour	68	60	11	38	21	2
Average	**72**	**60**	**20**	**34**	**8**	**6**

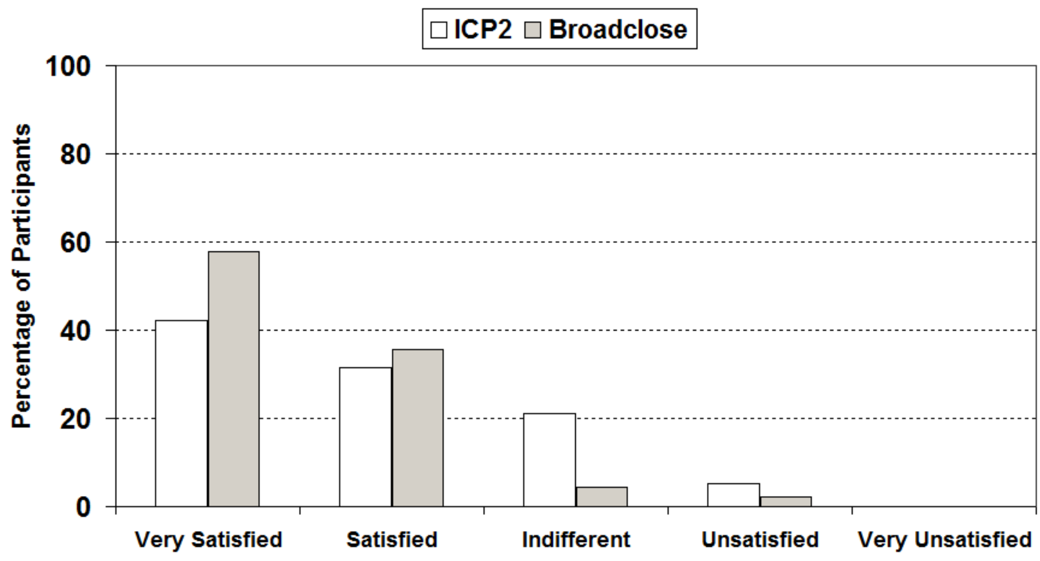


Figure 3.36 Overall satisfaction with WCs flushed by RWH

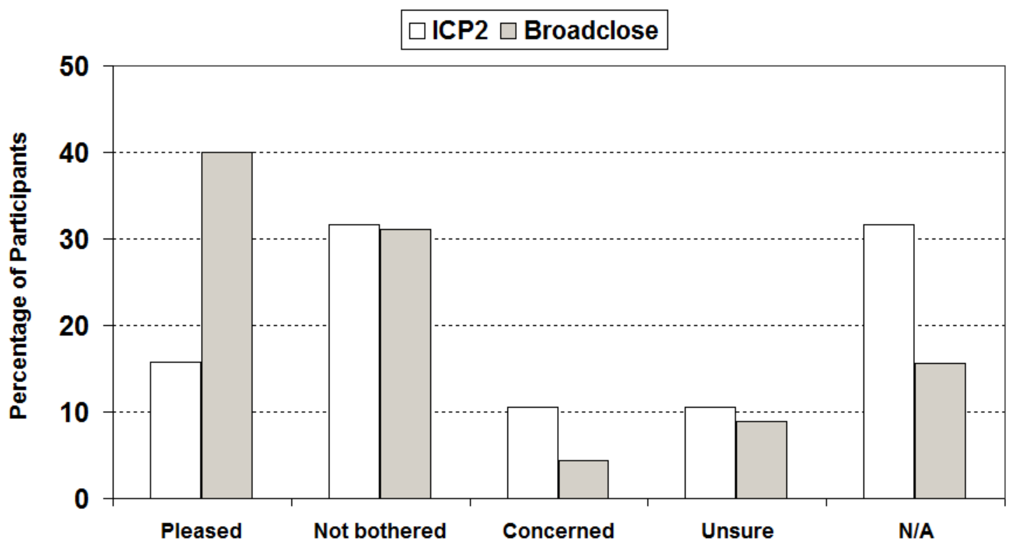


Figure 3.37 How participants felt about WC performance differences

After each question on performance, participants were provided with text boxes to make any additional comments on performance. A total of 48 comments were given, 8 from ICP2 and 40 from Broadclose, reinforcing the view that although Broadclose participants were '*not bothered'*, they had in fact observed a number of differences (in contrast to the result identified in Figure 3.37). The comments were categorized into positive and negative and sub-divided across the same themes as the performance question responses (Table 3.12), with only 1 comment falling outside of these themes. 9 positive comments were submitted between the two locations, most along the lines of '*no different to mains water*' with 1 commenting '*much quieter - very efficient*'.

39 negative comments were given, 33 from Broadclose and 6 from ICP2. The themes of negative comments (from both locations) are summarised in Table 3.13, in descending order of occurrence. As can be seen, almost half of the comments related to the water colour within the WC. These were along the lines of '*discolours toilet bowl*' or '*water is sometimes quite dirty after heavy rainfall*'. Both flush performance and water odour received similar numbers of comments and actual comments were variations on '*not as powerful*' for both locations and '*toilets here smell badly*' and '*needs a lot of air freshener near toilets as there is a noticeable odour*', for ICP2 and Broadclose respectively. In terms of power, it is unlikely that the RWH system is the source of the deficit; it is more likely to be the functioning of the WC itself.

Table 3.13 'Negative' comments received on aspects of WC performance (%)

	Percentage of Comments
Water Colour	46
Flush Performance	26
Water Odour	21
Noise Performance	3
Cleaning Performance	3
Other	3

Although these comments were categorized as negative in relation to WC performance, very few of them resembled complaints; they were phrased more as observations being reported and that could be overcome (by air freshener/cleaner), hence reinforcing participant's responses of not being overly concerned. Additionally, in some comments it was recognised that although there was a performance issue, it was not necessarily caused by the RWH system; for example:

'*difficult to know if the rainwater harvesting is the cause of any problems with the toilets*'.

3.3.10 Follow-up Interviews

As mentioned in Section 3.2.4.3, it was decided to conduct brief follow-up interviews with a small number of participants, in order to get feedback on how the questionnaire had been received. The aim was to expand briefly on some of the concepts that could not be probed in depth in a self-administered questionnaire. Due to the low number of interviewees (two), the transcripts were not subject to any formal thematic analysis (as in Chapter 4), but were simply examined for thoughts pertaining to the areas of interest.

3.3.10.1 Promoting RWH

Both interview participants agreed that RWH was needed, but differed in their views on how it should be implemented and promoted, based on the level of savings they had made compared with their expectations of what the system would provide. The first participant appeared frustrated that the communal system seemed to have low benefits to the householder, due to only being used to flush his WC:

'*we don't have baths, we do showers and it's only used to flush the toilet, not the washing machine, which uses a lot of water, or for outdoors watering the flowers or grass. It's a limiting factor, we only get 2% off our bill, I think its worth at least 10% if not more'*. He suggested that systems should be promoted for more high volume uses, such as washing machines: '*I'd be happy to use it in that*'.

The second participant also thought he had not made a huge saving on his water bill, but attributed this to other households on the same communal system using more of the rainwater:

'*one house might use it all over a weekend, I'd prefer my own system*'.

These comments reiterate the findings of the questionnaire; that financial savings are a primary concern to householders and that promoting the installation of combined-use systems should be encouraged, where appropriate. However, it also identifies that the installation of communal systems might perhaps not be suitable for all and therefore its inclusion within developments may require careful consideration.

3.3.10.2 Current Promotion

It was observed that the individuals interviewed were quite aware of RWH and other aspects of sustainable construction. They took part in activities which directly exposed them to such techniques, for example one noticed RWH in self-build magazines, on television programmes (Grand Designs) and at building-related events (Eco-build). However, he also identified that very little information was received without actively seeking it:

'*…don't see it advertised; get solar panel things through the door, but not for water*'.

This corroborated the previous suggestion that information should perhaps be provided by WSPs on customer water bills to increase the visibility of RWH. It was also felt that promotional activities were too slow:

'*well they do a lot of talking but there's not much action – need less obstacles. They could do with speeding up the process – takes forever - goes through parliament, Europe etc*'.

Additionally, one participant thought it was down to house builders and individuals to initiate the process:

'*…think new builds should have it…it's down to builders and contractors to start with new build, especially new properties and businesses, and then retrofit may be down the line when costs come down…also if people were more self-reliant and it was accessible and builders did it. You should get on and do it yourself, rather than waiting for someone to tell you*'.

3.3.10.3 Influence of the questionnaire

Both participants thought the questionnaire had made them aware of the systems supplying their houses:

'*yes, fact it is there makes me think of it every time I flush*'.

After careful consideration they also realised other adjustments they had made in relation to water use in general, such as considering a combined RWH and borehole system in a potential self-build project:

'*…little things like changing the programme on the dish washer and noticing how much the washing machine is using'*.

The main findings of the principal survey will be discussed after a brief description of the administration of the questionnaire to architects, so that the key messages from each can be summarised together.

3.4 Questionnaire to Architects

As mentioned at the beginning of this chapter, a supplementary survey to the main survey with house holders and office workers was conducted with architectural and construction design practices. This was in order to determine the current utilisation and practice of SWM technologies, such as RWH, at the building design stage. As outlined in chapter 2, introducing these technologies at an early stage in the design of a new build, or renovation, is crucial for their adoption.

3.4.1 Questionnaire Design and Construction

APART was utilised to construct the questionnaire and only online administration was used, due to time constraints preventing implementing a second large-scale dually administered (online and postal) questionnaire. As most architectural practices utilise Information Technology (IT) in their everyday work, only using online administration was not deemed to be particularly restrictive to accessing the questionnaire.

Previous work by Shirley-Smith *et al.* (2008), had briefly explored practitioner experiences with SWM technologies. The questions used within this work were used as a starting point for the present study. A full pilot study was not undertaken, due to resource constraints, but two architectural practices were consulted during the questionnaire development stage, in order to maintain the validity of any additional questions. The questionnaire was purposefully kept as brief as possible, in order to encourage a high completion rate. Questions centred on the use of technologies such as RWH and SUDS and knowledge of technical documents relating to them. An example of the questionnaire is located in Appendix B.

3.4.1.1 Participants

The Royal Institute of British Architects (RIBA) was contacted to ascertain if they would be able to assist in the study. This took the form of a request to forward a link to the questionnaire to their registered members. After several unsuccessful emails, followed by phone calls (which never seemed to get through to the right person), spanning the course of three months, it was decided that another course of action would be needed. The RIBA website contains a database of registered architectural practices that the public can search in order to identify an architect in their area. Several architectural practices from different areas of the country were chosen and contacted using both emails and follow-up phone calls. Subsequently, a link to the questionnaire was sent to a representative and that representative asked to forward it to any other suitable architects (either internal or external). The survey was conducted between November 2008 and May 2009. The locations, numbers of practices contacted and the number of responses from each location are summarised in Table 3.14. The 'other' location represents practices that had offices in more than one location, where a link was sent to several different offices. The number here represents the total number of offices contacted, not the number of offices relating to a particular practice. No further details of the practices are given, in order for participants to retain their anonymity in compliance with the ethics statement for the project (Section 3.2.1).

Table 3.14 Location of the practitioners contacted

Location	Number of practices contacted	Number of Responses
Exeter	6	2
London	6	2
Nottingham	3	0
Newcastle	3	0
Other	27	1
Total	**45**	**5**
Cooperation Rate		**11%**
Not completed		**7**

As can be seen from Table 3.14, unlike in the main questionnaire, there were several participants who started the questionnaire but did not complete it. As it is unknown how many individuals the online link reached, a response rate could not be calculated, but the cooperation rate was 11%. In comparison to cooperation rates for the main questionnaire, this was particularly low.

3.4.2 Results and Discussion

Statistical analyses were not undertaken as they would be potentially misleading due to the cooperation rate/sample number. The following sections summarise participant responses to the questions and derive key messages. However, due to the low cooperation rate, it was felt to be inappropriate to make substantial inferences from the data. Perhaps the most useful inference can be derived from the low cooperation rate itself. It could be suggested that some of the practitioners contacted were not motivated or were reluctant to participate in research into the utilisation of SWM, for whatever reason. Possible reasons could include the perceived validity of the questionnaire or a reluctance to disclose a practise's knowledge/activities. Alternatively, they may have been supersaturated with questionnaires, seen responding as a low priority or just may not have had time to complete it.

3.4.2.1 Awareness of SWM

Figure 3.38 illustrates the practitioner's awareness of different SWM techniques. The key to the labels on the Figure is given in Table 3.15.

Table 3.15 Key to labels on Figure 3.38

Label	Explanation
ABH	Abstraction borehole for water supply
GSHP	Ground source heat pump
EUAS	End-use appropriate source of water
RWH	Rainwater harvesting
Water Con	Water conservation measures such as dual flush WCs, waterless urinals
TWWT	Total Waste Water Treatment – onsite treatment of all waste water generated
GWT	Grey Water Treatment – onsite treatment of grey water
Green/GWR	Green or Grey Water Reuse
SUDS	Sustainable Urban Drainage Systems
IWMS	Integrated Water Management Scheme

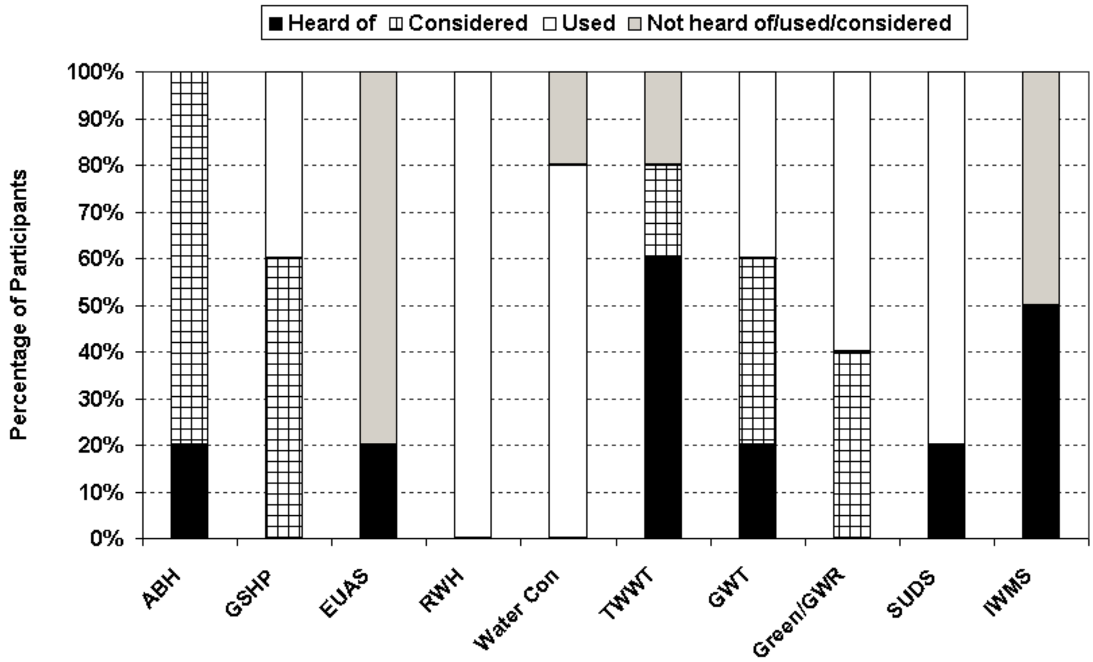


Figure 3.38 Participant's awareness of SWM techniques (see Table 3.15 for key)

From Figure 3.38 it can be seen that participants had heard of or considered most of the SWM techniques, with the exception of the end-use appropriate source of water technique. This is perhaps not surprising, as it has only recently been recognised by policy-makers and water professionals that water used for certain purposes (such as WC flushing) within a development does not necessarily need to be of potable quality.

3.4.2.2 Use of SWM

It was observed that a large proportion of the participants had used RWH, Green or GWR, water conservation measures and SUDS within a project. This suggests that such technologies are becoming more widely considered and implemented during the design and construction of new developments. The Code for Sustainable Homes, first introduced in 2006 (DCLG, 2006b), which encourages the use of such technologies, is likely to explain this trend. Participants were asked to give further details on the projects and these are summarised in Table 3.16.

A subsequent question asked participants to describe how successful they thought the projects that included the technologies had been. The results for this are summarised in Figure 3.39 Participants rating of the success of projects involving SWM. In general, for those that had utilised the technologies, water conservation, grey water reuse and SUDS projects were deemed to be successes. This is potentially explainable by the recent shift in the promotion, at a range of institutional levels, of such techniques leading to a certain degree of knowledge and experience in their implementation. In striking contrast, the majority of participants chose to not disclose how the RWH projects had performed and one participant responded that the project was unsuccessful. It could be inferred that the participant's reluctance to disclose the success, or failure, or the RWH projects in comparison to responses for the other technologies, was perhaps indicative of issues occurring during the design or implementation phases. Although this is pure supposition, the results from the other data collection activities undertaken for this thesis (particularly earlier in this chapter and Chapter 4), support the idea that there is a lack of knowledge and experience in implementing RWH systems. This is further reinforced by the participant that deemed the project unsuccessful, who commented that the technology was not brilliant and the project had suffered from teething problems.

Table 3.16 Details of projects using SWM provided by participants

Technology	Location	Details
GSHP	Totnes	Single borehole
GSHP	Twycross	At the HQ of a large computer software engineering company
RWH	Totnes	Technology was not brilliant, we had a few teething problems
RWH	Various	Numerous higher education and SWRDA* projects
RWH (& GWR)	London Brighton	Mixed use schemes – RWH is used for irrigation
Water Con	Various	Probably relates to 25% of the installations on all current projects
Water Con	Various	These tend to now be the norm; Most commercial developments have these, especially for BREEAM*; It is now standard practice to use low/dual flush toilets/aerated taps
GWT	Appledore	Used in a fish processing plant
GWR	Totnes	Water stained the sanitary ware
SUDS	Crediton Town Square	
SUDS	Various	This is now relatively common practice for us and has been widely used on lots of projects; Have used this where local drainage network does not have sufficient capacity

*South West Regional Development Agency; BREEAM = Building Research Establishment Environmental Assessment Method

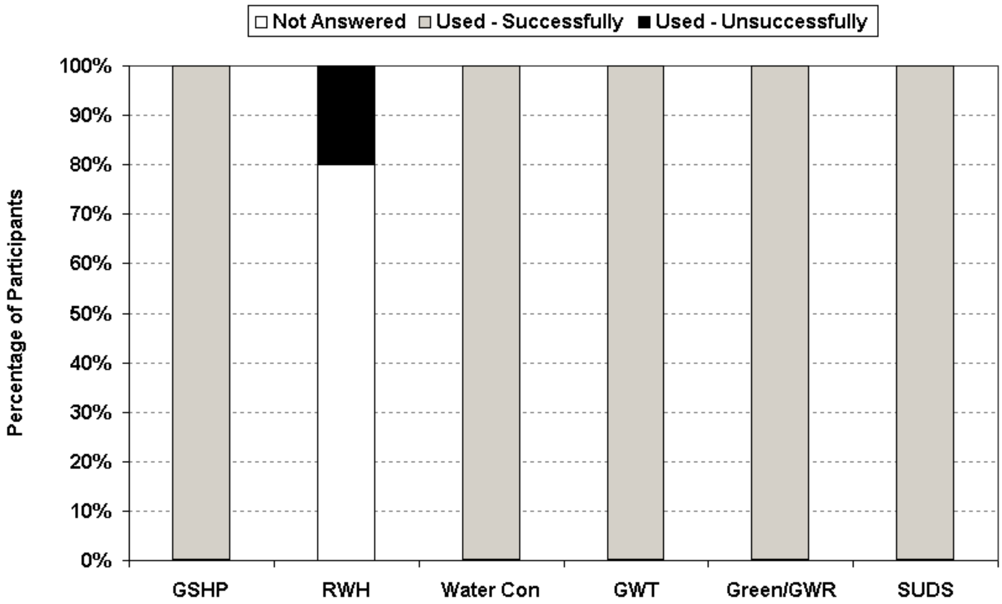


Figure 3.39 Participants rating of the success of projects involving SWM

3.4.2.3 Expertise and Information

The questionnaire further investigated the range of expertise within the practitioner's practices. Participants were asked if they had a practitioner with specialist building-related water resource knowledge within their practice and if specialist technical documents (such as the recent British Standard for RWH) were utilised. The responses are summarised in Figure 3.40.

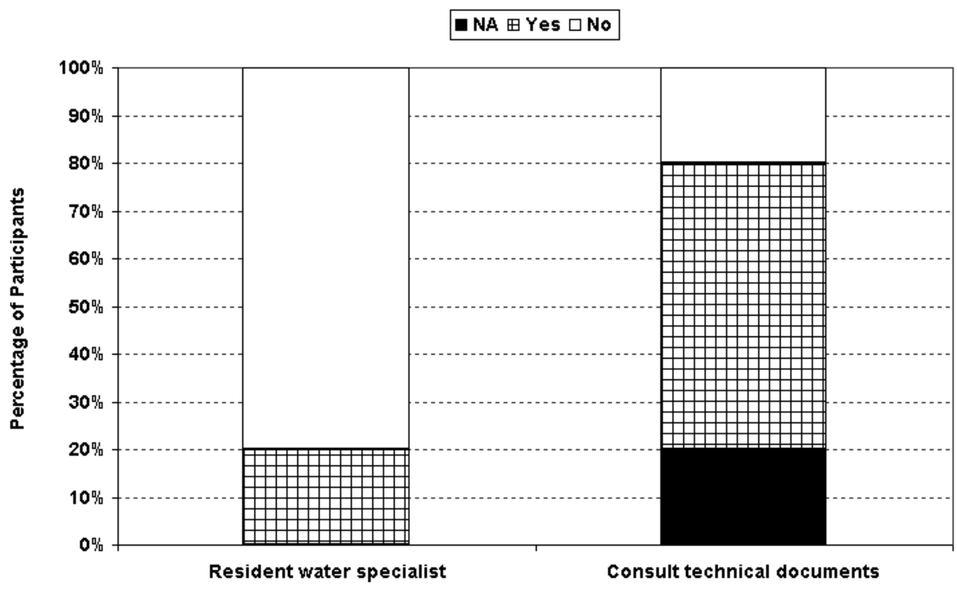


Figure 3.40 Expertise and documentation use in the participating practices

It was identified that although the majority of practices did not have a resident water specialist, technical documents were consulted during projects. The type of documents utilised was explored using a final question that asked participants if they had heard of a range of particular documents. A fictitious document title was included within this selection, to qualitatively assess social desirability bias i.e. to determine if participants would claim to have heard of the document to 'please' the questionnaire administrator. This document was entitled 'Project Report 1275: Rainwater and Greywater in Combination'. The results from this question are summarised in Table 3.17.

Interestingly only one participant claimed to have heard of and used the fictitious document. In contrast none of the participants had heard of the Texas Manual on RWH (TWDB, 2005), which is used as a model guidance document in the USA (and is easily located using Google). Reassuringly the majority of participants had at least heard of the British Standard, though the majority had not heard of the CIRIA series of documents or the EA's guidance. This is somewhat of a concern as the CIRIA documents have been in existence for nearly a decade and provide the most comprehensive guidance to RWH. They are however, very expensive to purchase (the only way of obtaining them, unless a 'pirate' copy is accessed), which may reduce the number of practitioners using them.

The cost aspect is also true of BS 8515:2009, but as this is more recent and has been highly publicised, the perception may be that it is worthwhile for companies to purchase it. It also contains a large volume of material derived from the CIRIA work, though obviously not in as great a depth as the four CIRIA documents provide. Of particular concern is that the majority of participants had not heard of CIRIA document C626, on the management and maintenance of RWH and GWR systems. This is a document that provides a model for documenting responsibilities and schedules for undertaking maintenance activities, which are crucial for the ongoing effective operation of systems. The deficit in knowledge of this series of documents may help to explain the findings outlined in Chapter 4, where SMEs felt that the knowledge and expertise of the so-called 'experts' was lacking.

Table 3.17 Participants knowledge and use of guidance documentation

	Heard of, not used (percentage)	Heard of, used (percentage)	Not heard of (percentage)
BS 8515:2009	40	20	20
CIRIA TN7	0	20	80
CIRIA C539	0	20	80
CIRIA PR80	0	20	80
EA	20	40	40
CIRIA C626	0	20	80
Texas RWH Manual	0	0	100
RWH&GWR 1275	0	20	80

3.4.3 Summary

Interesting observations have been made by conducting a brief, but detailed questionnaire with building and development practitioners. However, due to the low cooperation rate, further research would perhaps be required to identify if these observations are widespread at this institutional level. The key message is that although practitioners are increasingly aware of and are implementing SWM technologies, due to apparent regulatory and code (CfSH) compliance, their level of knowledge regarding implementation documentation is limited.

3.5 Chapter Summary and Key Messages

3.5.1 Summary

This chapter presented the results of a survey administered to householders located in residential and commercial developments, as well as a supplementary survey of building design practitioners. The primary research question and sub-questions posed at the beginning of the chapter have been answered and are summarised below. A number of key messages have been derived, which are also summarised below.

1) Are participants' aware of water saving devices in general?

Overall, the majority of the 106 participants had used one or more of the suggested water saving devices, ranging from a hippo (water displacement device) to a RWH system. The most popular device was a dual flush WC. In general experiences with such devices were positive.

a) Do they have awareness of or experience with RWH?

It was discovered that man of the participants at one of the commercial locations with a RWH system, did not know (were not informed) the building in which they worked had a RWH system for flushing WCs. In contrast, a small percentage of participants at one residential location had used RWH systems. In the majority of cases where a RWH system had been used, experiences were rated as positive.

2) How acceptable are a proposed range of sources and end uses?

The less control a participant had over the source of rainwater or greywater, the less acceptable it appeared to be. Additionally, inline with previous studies, the acceptance of and risk associated with a range of end uses considered by participants decreased as the activity became increasingly personal.

a) What risk value do participants assign to these?

Outdoor uses, including gardening, washing the car and bathing animals received risk ratings of less than 5 (from a scale of 1 to 10). More personal uses, such as clothes washing and washing vegetables received risk ratings greater than 5.

b) Do these differ between users and non-users?

There were no statistically significant differences between user and non-user risk ratings.

3) From where (if anywhere) do/have participants source/d information on RWH?

Very few participants (either users or non-users) had sourced information on RWH. Those that had used a variety of sources, illustrating that householders are not certain about where is best to locate information.

a) Where do participants' view the most appropriate place to obtain information?

The two most popular places from which to obtain or receive information were with a water bill and via the internet.

4) What factors are most important for encouraging consideration of implementing RWH?

The two most important factors were receiving a grant or subsidy and saving money on water bills. This highlights that financial incentive remain a primary concern of householders. Beyond financial incentives, there was a high degree of variability for other factors (such as promotion by various groups, or restrictions on water use). This indicates a high degree of uncertainty regarding other factors encouraging the implementation of RWH.

a) How do they rank?

Overall, grants/subsidies and saving money on water bills ranked first and second, respectively. The third most popular response was 'Don't Know', followed by a water shortage and helping the environment in fourth and fifth, respectively.

b) Do these differ between users and non-users?

Receiving a grant/subsidy and saving money on water bill ranked first and second, respectively, for both users and non-users. The third highest for users was new policies/laws and for non-users was 'Don't Know'. This reinforces that, beyond financial incentive, there is a high degree of uncertainty regarding the factors that would encourage householders to implement RWH.

5) What are participant's views of RWH?

a) Do they think RWH is a good thing?

Overall the majority of participants thought that RWH was a good thing.

b) How aware are participants' of maintenance issues?

Although the majority of participants agreed that maintenance was important, there was limited awareness of the frequency with which activities should be conducted, as well as their importance and associated cost.

c) What are the perceived benefits of RWH?

The majority of participants appeared to be aware of the benefits presented. For example, connecting RWH with a potential flood alleviation benefit. It was also highlighted that those with RWH systems felt they were 'doing their bit for the environment'. However, the social desirability bias of these responses was felt to be high and therefore it is difficult to infer too much from this section of the questionnaire.

d) Do opinions or knowledge differ between RWH system users and non-users?

In general, user and non-user opinions and knowledge regarding benefits and maintenance activities were very similar. Only one difference arose, which was in their perception of the importance of cleaning the catchment area, with non-users rating it as less important for water quality.

e) How do users rate the performance of WCs flushed with RWH?

Overall, users were satisfied with the performance of WCs and not concerned about any differences they had observed. The most common observation was that the water in the pan was often discoloured, often following heavy rainfall.

This allows the main research question for this chapter to be answered:

- Is the UK public aware of and willing to implement RWH?

The householders and office tenants surveyed showed varying degrees of awareness and willingness to implement RWH. Some participants were not aware of RWH systems within their place of employment, but others had experienced systems outside of their everyday life. Overall receptivity to the idea of using RWH was positive for a wide range of uses, though the risk associated with each increased as the use became increasingly personal. Participant's willingness to implement RWH showed potential for being compromised due to the commitment and costs associated with maintenance activities and uncertainty in factors that would encourage them to install a system. However, financial incentives (indirect and direct) and information from water companies were two factors which received unanimous support from participants.

Additionally, limited insight has been provided into the knowledge and awareness of building design practitioners to RWH and its associated documentation. The research question (are building design professionals aware of RWH and the appropriate design documentation associated with it) has been answered with the discovery that although practitioners are increasingly aware of and are implementing SWM technologies, their level of knowledge regarding implementation documentation is limited.

3.5.2 Key Messages

(1) Although householder experience with water saving devices is good, the presence of RWH systems in UK developments is not being widely publicised by organisations responsible for the developments;

(2) Agents responsible for designing new developments should be encouraged to consider the use of communal and combined-use RWH systems, where appropriate. Such systems have the potential to increase both the financial and environmental viability of installations. Extending promotion of RWH as being suitable for laundry activities may require extra householder engagement activities, to reassure some potential system installers/users about the risk associated with such usage;

(3) A central, independent and reliable source of information needs to be identified if RWH is to be better promoted inline with the direction of recent policy documents. There may be an opportunity for relevant organisations to undertake partnership working to provide such a facility by promoting a well-maintained 'central' website via WSPs customer's water bills;

(4) Financial incentive schemes (such as ECA) may need to be extended to non-business entities, to encourage wider consideration of installing a RWH system.

Additionally, recent changes to some WSP waste water/surface water drainage charges should be more widely promoted i.e. honesty regarding drainage costs. Beyond the provision of financial incentives, there is an uncertainty as to the type of factors that would encourage consideration of installation of RWH in households. This indicates that further research is required to fully investigate household motivations, to understand how to provide appropriate support services, if there is a desire for domestic RWH to become more widely implemented;

(5) Greater engagement with householders is required to increase knowledge and awareness of maintenance activities and their associated costs, to increase their receptivity to RWH, to increase its acceptance as 'mainstream' rather than 'novel'. Additionally, innovation in RWH system design may be required in order to reduce the commitment and cost required to make systems more attractive to the user. Furthermore, the performance of WCs fed by RWH systems should be regularly assessed, to maintain user's confidence with systems. Increasing awareness and consideration of first flush devices may be required, to reduce potential rainfall flushing effects on WC aesthetics;

(6) Practitioners are increasingly aware of and are implementing SWM technologies, but their level of knowledge regarding implementation documentation is limited.

One final key message was derived from undertaking follow-up interviews:

(7) Information gathering activities can form part of the engagement and awareness raising process (action research) when conducted in stages and over a long duration.

It could be argued that the the issues highlighted by the survey are not necessarily specific to householders and office tenants. For example, the provision of adequate guidance and advice could be transferrable to other installations, such as business establishments. In order to provide a certain degree of triangulation ('"*using more than one research method to home in on a particular phenomenon*", Hayes (2000)) for the findings of the survey, interviews with SMEs were undertaken simultaneously. The results of these interviews are discussed in the following chapter. The key messages from the present chapter will be re-contextualised in Chapter 7, in terms of themes identified in the literature review and key messages from proceeding chapters.

4 CHAPTER 4: UNDERSTANDING STAKEHOLDER RECEPTIVITY – SMALL TO MEDIUM ENTERPRISES

4.1 Introduction

The previous chapter explored the receptivity of householders and office tenants to RWH. However, it was identified in the literature review that many different stakeholder groups are potentially willing to implement RWH, but their ability is restricted. Therefore the receptivity and ability of a second stakeholder group was investigated, that being small to medium enterprises (SMEs). In order to assess the receptivity of SMEs and to identify how they could be further encouraged and enabled to implement RWH, the following research question was posed:

- How have SMEs found the RWH implementation process?

This was subsequently broken into more manageable questions, which could be used to develop an interview schedule to use with interviewees. These questions were:

- Where do SMEs source information on RWH?
- What support is available to facilitate SMEs in considering/implementing RWH?
- Are there obstacles discouraging SMEs from considering/implementing RWH?

This chapter describes interviews undertaken with a group of SMEs in Devon, UK and is divided into the following main sections:

- **Interview Method;**
- **Analysis;**
- **Results and Discussion;**
- **Chapter Summary and Key Messages.**

4.2 Interview Method

4.2.1 Overview

In order to answer the questions outlined above, it was decided to undertake focused interviews with representatives from SMEs. The aim of the interviews was to conceptualise potential areas of deficit in supporting RWH implementation. As such they were more focused on eliciting representations than mass replication of responses (Oppenhein, 2005). Focused interviews permit the expression of interviewees' thoughts and feelings, whilst still affording the interviewer a certain amount of control over how the interview progresses (Robson, 2002). It was decided to use focused interviews, to allow flexibility of discussion and minimise as far as possible any power differentials between researcher-interviewee (Sefton, 2009). Focused interviews are also appropriate when interviewees are being sought who have direct involvement with particular situations – such as RWH in this study.

It was decided to perform interviews rather than conducting a survey, as a survey would not lend itself well to really understanding the SME point of view or full experience (Oppenheim, 2005). Robson (2002) describes collections of words as "*rich*", "*full*" and "*real*" – in opposition to the "*thin abstractions of number*." By conducting interviews greater insight on the ideas and feelings of the SMEs could be derived than from simple direct survey questions, even if they were left very open-ended. Oppenheim (2005) asserts that interviews help participants to say what they think with greater richness and spontaneity, as well as in helping to avoid misunderstandings. Additionally, spending some time with the SME would increase the visibility and commitment of the researcher. This would hopefully engender a greater trust and therefore more valuable open discussion with the SME than gathered by completing a faceless distanced questionnaire.

4.2.2 Sampling and Interviewee Identification

Initially, consideration was given to interviewing representatives of the following groups:

1. SMEs which had not heard of RWH;
2. SMEs which had heard of RWH, but no more;
3. SMEs which had heard of RWH and tried to implement it, but unsuccessfully;
4. SMEs which had heard of RWH and implemented it successfully.

However, in devising an interview strategy, it was determined that performing several (3 to 4) interviews within each category would not be feasible with the resources available. In addition, scoping exercises for SMEs to approach for interview revealed it was not as easy as initially thought to identify SMEs in all of these categories. As such the strategy was revised to focus on groups 3 and 4 (hereafter referred to as 'non-implementers' and 'implementers', respectively). This was felt to be justified, as these groups would potentially provide the most detailed information about the pre, during and post implementation stages.

As the two groups for which interviewees were being sought were very specific, sampling could only be purposive, that is it was the selection of cases that would highlight the queries under consideration (Pattern, 1990). It was also a semi-quota sample (Robson, 2002), as it was decided that 3 interviews should be the minimum undertaken per group and that they should be representative of businesses found in most geographical areas.

A number of UK-based RWH system manufacturer and suppliers have detailed case studies from installations they have undertaken on their websites. Consideration was given to approaching potential interviewees via this method, as their details were already within the public domain and therefore data protection issues could be averted. However, in approaching potential interviewees it is advisable to disclose how the researcher has come into possession of their contact details. In this case there existed the possibility that an association might be made between the interviewer and the manufacturer/supplier. This had the potential to provide either a positive or negative bias within the interview towards this manufacturer or supplier i.e. greater or less mention of them.

Keeping this in mind, an independent party, Global Action Plan (Hodgson, 2008) was approached. GAP is a charity who assists a range of stakeholders in undertaking tangible and practical sustainability projects. They had recently undertaken a project involving SMEs. As such, they had access to a database of SMEs who had undertaken RWH implementations, or had attempted them. The database was not subject to normal confidentiality clauses, as the SMEs had agreed their details could be used for other purposes (Store, 2009).

4.2.3 Arranging and Conducting Interviews

In total, the GAP database contained contact details for 17 SMEs (in the Devon area) that had either tried to implement or had successfully implemented RWH. As not all SMEs could be interviewed, it was decided to divide the 17 into groups based on the nature of their business (hotel, café, farm etc) and to approach a number representative of each group. Different contact details were given for each, some email addresses and some phone numbers. Therefore two different methods were used to contact the SMEs. However, the first contact was standardised across both methods, by following an introductory script (Appendix C). This outlined how the researcher had obtained their details, confirmed that the potential interviewee had either considered or implemented RWH, the purpose of the research and an invitation to participate in an interview in relation to their experiences with RWH implementation.

Each interviewee was informed the interview would last somewhere in the region of an hour. In total 12 of the 17 SMEs were approached and 7 agreed to participate. This was identified as being acceptable for PhD research (Barr, 2009). In compliance with the code of ethics followed for this research (described in Section 3.2.1 and full form located in Appendix B) the individuals interviewed and the business name of their company are not referred to directly. Instead they are referred to by transcript number to preserve their anonymity. However, to give the reader an idea of characteristics of the SMEs are summarised in Table 4.1. A map showing their geographical locations is illustrated in Figure 3.7 (page 141).

A mutually agreeable date and time was determined for the author to visit each SME at their premises. Conducting the interviews on the SMEs ‘home ground’ increased the flexibility of the interview, facilitating maximum participation. In addition, it meant that the SMEs were in familiar, comfortable territory, thus making the interview less threatening. Furthermore, it afforded the author an opportunity to fully visualise anything discussed in the interviews relating to the installed RWH system or problems in installing a system. Interviews were conducted between March and June 2009. Only one interview had to be rescheduled.

Table 4.1 Characteristics of the interviewed SME sample

Transcript Number	Type	Number of employees	RWH?
1	Farm/Shop/Café/Education Centre	25+ (varies seasonally)	Y
2	Animal charity	100+ (varies seasonally)	Y
3	Office	110 (capacity = 300)	Y
4	Hotel	12	Y
5	Cafe	3-5 (technically a 'micro' enterprise (<10 employees))	N
6	Specialist craftsman	15	N
7	Charity (with working dairy)	50+ (varies seasonally)	N

Interviews were not recorded using audio equipment, for two main reasons. Firstly, to maintain the informal focused interview style; Robson (2002) asserts that tape-recording some types of interview can affect spontaneity. Secondly, two potential interviewees had asked, when first contacted, if they would be recorded. The author detected that if a 'yes' reply was given the prospective interviewees would have declined to participate. As the population available for sampling was already quite restricted it was decided to maximise participation as far as possible and so a 'no' reply was given. Both potential interviewees expressed relief to this reply, for unknown reasons and given their reactions it was not felt appropriate to ask for reasons. Therefore in order to maintain consistency no interview was audio recorded. However, potential interviewees were informed that detailed notes, including verbatim quotations, would be taken and were asked if this would be acceptable. All interviewees who eventually took part found this perfectly acceptable.

As per standard ethical practices (Section 3.2.1), interviewees were informed that the interview notes would be anonymous and confidential. In addition, at the end of each interview, interviewees were shown the interview notes and asked if they agreed they were an accurate representation of the interview. None of the interviewees disagreed and were happy for the notes to be analysed within the research. With respect to this, it could be argued that the transcripts are more akin to field notes from participant observations. However, the author would argue to the contrary, that the depth captured in the notes is equal to that derived from transcribing an interview tape as most responses were recorded verbatim. As such the outputs from the interviews will subsequently be referred to as ‘transcripts’.

Sources of bias, such as significant rephrasing of questions and inappropriate prompting, were kept to a minimum by following the devised interview discussion guide (described in detail in Section 4.2.4). This was also true of topic sequencing, except in cases where the interviewee naturally diverged from one topic onto a topic that was further down the guide. In such cases the interviewee was left to talk in the tangential direction to prevent their thought process from being interrupted, so that as natural a response as possible was given. If this occurred the interviewee was asked if they had anything to add regarding the tangential topic, when the interview progressed to the position it appeared on the guide. However, care was taken to diplomatically prevent too much time being spent on unnecessary tangents unrelated to guide topics.

As RWH is still embryonic in the UK and although uptake is increasing it is still slow, in choosing to interview SMEs, a certain preconception was held that their perceptions and experiences would relate to difficulties in implementation i.e. barriers, as these are most commonly referred to in the literature, rather than 'strengths'. As such the interviews had to be conducted without direct reference to this preconception. The author was careful not to use the word 'barrier' or 'hurdle', due to the connotations these conjure up. As such, reflexivity was incorporated into the research design. Indirect modes of investigation regarding any barriers or hurdles were undertaken, such as asking generally about how they had found the process and asking to elaborate on what (if anything) had gone right or wrong and how they felt about it.

4.2.4 Interview Guide

Focused interviews are, in some ways, more difficult to conduct than standardised interviews. The interviewer has to ensure that the interview is kept on track and tangential conversations do not detract from the subject of discussion and the main purpose of the interview. However, the interviewer also has to maintain some consistency in the way topics are introduced and in providing non-directive guidance (i.e. avoid leading questions and to interfere as little as possible), (Oppenheim, 2005).

As such an 'interview guide' was formulated by devising a range of possible topics, based on the research question and conducting a pilot exploratory interview with an SME that had undertaken a RWH system implementation. A range of question types were incorporated within this pilot schedule, including factual ('Where did you obtain information on RWH') and opinion ('How did you find the process overall'). As two different groups were being interviewed, implementers and non-implementers, there were slight differences between the interview schedules, as some questions would not be relevant to both groups. For example, there would be no point in asking implementers 'Why was a system not suitable', as they had had a system installed and so obviously it was suitable. Additionally, as non-implementers had got as far as they could in the process before determining RWH was not suitable, it was felt appropriate to ask direct questions as to why and how the situation could have been improved. This was felt appropriate as such information would provide insights into whether the problems experienced could have been overcome and if so, what was required to overcome them.

The final guides consisted of 11 topics for the implementers and 10 for the non-implementers (Table 4.2). 7 of the topics were common between the two schedules. Additionally, 'probes' were used within each topic in case interviewees were not forthcoming after a new topic was introduced (examples of interview schedules are located in Appendix B).

4.2.5 Ecological and External Validity

The interviews were conducted with SMEs who had either been through the implementation process and/or tried to pursue the implementation process. Therefore the ecological validity (the degree to which recorded observations reflect real life (Robson, 2002)) of the study could be regarded as high, as the findings directly relate to real life experiences.

Table 4.2 Interview Guide Topics

	Implementers	Non-implementers	Probe/s
1	Where did you first hear about RWH?	Same	
2	Why did you decide to install a RWH system?	Same	
3	Where did you access information?	Same	How did you find this?
4	How was/who designed the RWH system?	Did you investigate system design or technical aspects?	Implementers - What were the technical specifications? Non-implementers – Supply-demand balance; maintenance requirements/cost; water quality; were resources adequate to enable you to do this? Did you know where to find information?
5	How did you find the process overall?	Same	
6	What support did you have along the way?	Same	From who?
7	How long did it take to complete the process?	Same	
8	How could things have been improved?	Why was a system not suitable?	Simple, complicated or a mixture? What went smoothly, what didn't? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?
9	Has system performance met your expectations?	What could have been done to improve chances of implementation?	Non-implementers – If nothing, why? If something could have been done, why wasn't it?
10	Do you use the fact your business has a RWH system as a promotional tool?	Closing section – anything else?	
11	Closing section – anything else?		

However, as the interviews were only conducted in one geographical area (that being Devon) it could be argued that the external validity and potential for spatial generalisation of the research is limited. Although both rural (interviews 1, 6, 7) and urban (2, 3, 4, 5) and new installation (interviews 2, 4, 6) and retrofit (interviews 1, 3, 5, 7) cases were represented. This lends well to generalisation across these contexts and therefore threats to external validity, such as setting and construct effects (Robson 2002), were minimised. Several avenues were pursued to try to increase the external validity of the study further by including a second geographical area (London). These activities included:

i) Contacting the Global Action Plan linked London-based ‘SmartWorks’ project, to use the database of SMEs they had helped consider/install RWH;
ii) Contacting Envirowise for reasons the same as above.

After lengthy liaisons and delays, it was determined by SmartWorks that there were no suitable case studies that details could be provided for. Where there might have been, the SME did not want to be involved as they did not think they could be of much help. Reasons for this were not given and it was not clear why they thought this. Efforts were made to persuade them to the contrary, but after several attempts these avenues were not pursued further due to fear that the content and thus validity of the interviews would be compromised.

4.3 Analysis

Initially, a hierarchical thematic analysis approach was considered. This is the most common approach to analysing rich interview data, where concepts and constructs are devised and placed on a tiered network where one stems from another (Robson, 2002). However, as the author became more enveloped in the data, it became apparent that there was not a naturally occurring hierarchy between the concepts emerging – many concepts developed in parallel and displayed equal weightings. As such, the analysis naturally diverged into template analysis. Template analysis involves the construction of lists of words that occur within each transcript. These are then grouped into common themes and the ‘template’ reapplied to the transcript to validate the developed themes. Template analysis emerged as being more appropriate as it is still data driven but affords greater flexibility in concept development. It also allows some consideration of *a priori* and non-hierarchical themes (King, 2004).

Deductive thinking was used in manually conducting template analyses of each interview transcript, which involved the open (associative), axial (interconnective) and selective (core) coding of ideas and concepts present within the text (Robson, 2002). This was conducted using highlighter pens and the construction of tables within a Word document to record the occurrences of each code and associated quotations. As general and specific aspects of the RWH implementation process were the subject of discussion within the interviews, this heavily influenced the analysis. The main aim of the interviews was to identify areas of implementation deficit and although no *a priori* categories were determined, the author had to remain faithful to the data and to not bias the derivation of the categories. Therefore the analysis was grounded in the experiences of the interviewees and the data was constantly reviewed, revisited and reframed during the analysis. Analysis was an iterative process, consisting of a number of 'passes' of the transcripts, during which the author was able to fully engage with the text and develop codes (themes) to categorise concepts. Each pass involved identification of key words and sentences within each transcript relating to issues occurring within the implementation process.

During the first pass of the transcripts lists of words and anchors (codes) within each transcript were constructed. These were then compared and commonalities began to emerge between transcripts, but it was clear further passes were required to fully understand the levels at which the codes were operating and refine their wording. It is important to mention at this juncture that neither contextual constructivist nor discursive viewpoints were taken by the author. That is, it was not assumed that multiple interpretations of the data would be possible or that there were significant diversities of meaning in the text (King, 2004). As the topics within the interview guide were focused specifically on uncovering experiences with the RWH implementation process, it is unlikely that the content of the interviews would depart significantly from that subject (assuming the interviewer maintained relative control of the subject of discussion).

The second pass involved constructing a list of common codes and re-examining each transcript for the presence, or absence, of both individual transcript codes and the common codes. Care was taken to ensure the data was being *interpreted* and not merely *summarised* – a particular hazard in this type of analysis (Robson, 2002). This led to a more refined list, in terms of the number of codes, their description and the representativeness and commonality of meaning across the interviews. Transcripts were again re-examined for their presence. Each pass involved the insertion of new codes, the deletion of others and the rewording of others to accommodate new pieces of text along similar themes. After this the codes were fully reconceived as higher level concepts embracing fully the aspects of the implementation process highlighted by the transcripts. At this point further passes yielded increasingly diminishing returns in terms of new or different codes. At this point it was also decided to use the qualitative data analysis (QDA) software package 'NVivo' (QSR, 2009) to manage the data, as the number of linkages between codes in each transcript were becoming cumbersome to represent using highlighters and Word-based tables. This also permitted a certain level of cross-coding, as this activity could not be undertaken by another researcher due to the required commitment (time, finance).

Interview transcripts were imported into NVivo and a first-level 'tree node' for 'Implementation Deficit Categories' was created. Second-level ('branch') tree nodes were created for each of the 5 previously identified IDCs. In the same way that transcripts were manually coded, they were coded within NVivo using the 'Code Selection-At Existing Codes' function, where text was assigned to one of the five IDCs. In this way it was possible to directly reassess the validity of the IDCs: if text could not be coded to any of the IDCs (and was not related to other topics, such as drivers for implementation, or was not normal 'conversational' text) then the IDCs could not be seen as a comprehensive representation of the data. A small amount of recoding occurred within NVivo, but this mainly centred on the appropriateness of the wording of the IDC titles. No further level nodes were required - as previously mentioned, a natural hierarchy did not emerge from the data. The IDCs derived did not necessarily nest within a hierarchical structure – they seemed to hold relatively equal relevance and prominence for the interviewees. However, there was a significant amount of axial coding between them, which will be discussed further in the following results section.

In terms of conventions of reporting, where a direct quotation from a transcript is used to illustrate a particular IDC, only the transcript number and page number is given (transcripts are located in Appendix C) in order to maintain anonymity.

4.4 Results and Discussion

Initially the interviewees were asked about why they had considered implementing RWH, or why they had implemented it. The main drivers identified were:

i) To save money;

ii) To save water;

iii) To demonstrate sustainability;

iv) To avoid wastage.

The first three were anticipated as it makes financial sense to save water, as it saves money (due to SMEs generally being metered) and in the current market it is good to be seen as 'green' and promoting/demonstrating 'sustainability'. However, the last driver was not anticipated. Wastage of rainwater proved to be a concern to the SMEs - several had large plots of land on which their premises were based and during heavy rainfall they were frustrated by seeing large volumes of runoff disappearing into drains; they viewed it as wastage. They wanted to capture the runoff and reuse it to supplement their non-potable requirements. Additionally the SMEs interviewed showed a good knowledge of having an appropriate quality of water for particular intended end-uses. For example, in addition to all wanting to use RWH to flush toilets, one wanted to use it to wash down dairy cattle and two wanted to utilise it for washing down concrete areas.

The rest of the interview content centred on the implementation process itself. As analysis was undertaken at deeper and deeper levels, common themes began to emerge, highlighting 'weak' areas of the process, relating to the interviewees direct experience. Such themes were also common across the interviews. As such it was decided to term the 'weak' areas 'implementation deficit categories' (IDCs) and analysis continued to identify common IDCs across the 7 interviews.

Describing the deficit areas that have been identified is a complex process, as they naturally intertwine and many cut across categorical assignments. However, this was attempted with the use of a process map, to represent not only the deficit categories, but also their interaction in relation to the stakeholders involved in the implementation process. The explanation that follows is an attempt to articulate verbally the implementation deficits identified and the stakeholder interactions evident in the overall process, schematicised in Figure 4.1.

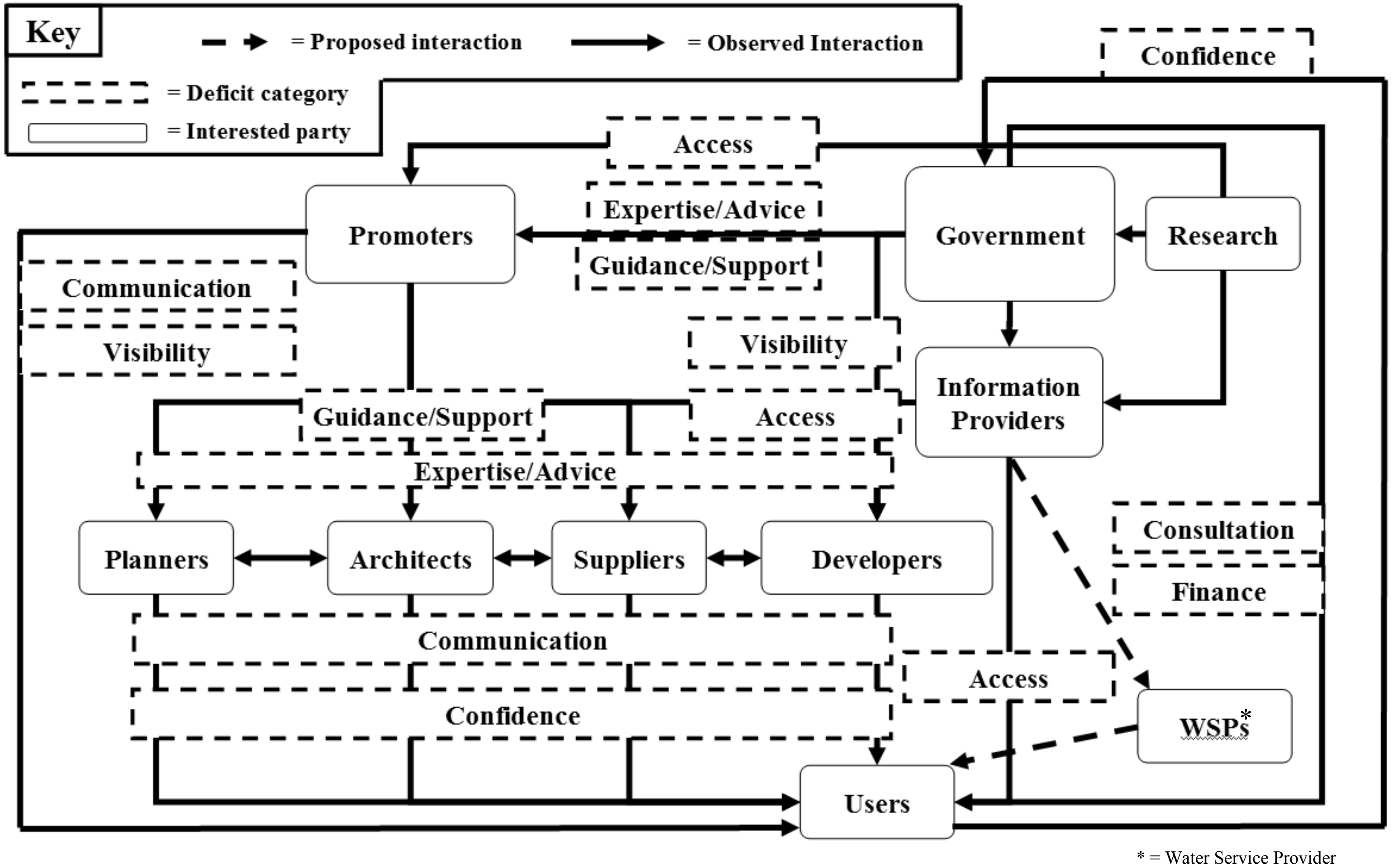


Figure 4.1 Implementation Deficit Categories and their interaction with RWH stakeholders

At the highest level of the hierarchy, it was identified that implementation of a RWH system is split into three parts - design, installation and post-installation/maintenance. Although these parts are trying to achieve the same aim - that being the provision of a fully functional RWH system - they are three entirely separate activities. This was identified by examining the stakeholders involved with the three parts of the process. From the interviews it was identified in 5 out of 7 cases that there were multiple, or the potential for multiple, stakeholders involved across the three parts of the implementation process. Only in two cases, where there was deemed enough in-house expertise to do all parts (Transcripts 3 and 7), were the activities treated as one, with one person responsible for the entire process. On examination of the range of stakeholders involved in the entire process, it became apparent that some were only involved with the feasibility assessment and design of a system, then upon installation this changed and a different range of stakeholders were brought in to operationalise the system, then upon completion and commissioning a further set of stakeholders were brought in to provide maintenance.

The three parts of the process provide useful boundaries to identify implementation deficits, as problems with and issues relating to implementation were split into the three areas. For example, system designs (for both implementers and non-implementers) were plagued by inappropriate sizing and siting due to poor consideration of the appropriate variables, such as demand and local conditions. Installations (implementers only) were frequently delayed due to a lack of communication between stakeholders involved and a lack of ability in actual technical installation. Furthermore, post-installation problem-solving and maintenance was dogged by an unwillingness to accept ownership of faults, inadequate knowledge of maintenance activities and not establishing a maintenance schedule. Additionally, for both implementers and non-implementers, it was identified that capital outlay was an issue for initiating a project, as was a lack of confidence in and suspicion of manufacturers and suppliers.

Although problems and issues identified related to specific parts of the process, it was observed that most of the issues observed could be attributed to common causes. For example, inadequate consideration of system design variables, a lack of technical ability in installation and poor knowledge of maintenance activities suggested that stakeholders involved in these parts of the process were perhaps not aware of, or did not have access to, appropriate guidance and support. Overall this represents a significant deficit in expertise. By examining in detail cases where there have been issues in the process, it has been possible to determine over-arching implementation deficits relating to the entire implementation process. These are:

1) Expertise and Advice (E&A);
2) Guidance and Support (G&S);
3) Visibility and Access (V&A);
4) Confidence and Communication (C&C);
5) Finance and Consultation (F&C).

It is only to be expected that these categories do not stand alone - for example a lack of expertise can result in a low confidence. However, in the interests of clarity of understanding and to fully explain the origins of the deficit category titles, they will be discussed separately. In addition, when designing the interview discussion guides, sections were included that facilitated elucidation of suggestions from interviewees on how the implementation process could be improved. In relation to this, recommendations are made based on the direct and indirect suggestions of the interviewees. These are collectively outlined under each IDC section and entitled 'responses and recommendations'. In the interests of clarity and consistency, hereafter each SME interviewed will be referred to as an ‘interviewee’.

4.4.1 Expertise and Advice (E&A)

Expertise was lacking in two contexts. Firstly, in five out of seven cases the interviewees themselves did not believe that they had enough expertise regarding water-related issues to either source information about RWH themselves:

“*Needed to know so much about all this technical stuff, which was all too much, both time and stress-wise*” (Transcript 6)

Or to project manage the system installation themselves and they found themselves:

“*Making it up as we went along”* (Transcript 1)

This led to a dependence on other stakeholders. As such, both implementing and non-implementing interviewees reported that they generally left it to the experts when designing, installing or maintaining a RWH system.

However, secondly, they felt that the supposed experts were:

"*...learning as they went along*" (Transcript 1)

And:

"*Helped each other muddle through*" (Transcript 1)

As such they were left:

"*...feeling like the guinea pig*" (Transcript 5)

This indicated those implementing the systems did not necessarily have the technical expertise or enough previous experience in carrying out designs or installations. Such a concern was voiced by one of the two interviewees who had performed the design and installation of the RWH system themselves (due to being a plumber by trade). The interviewee had been on:

"*...an extra course to bring myself up to speed*" (Transcript 3)

But was concerned that not many other plumbers would undertake such activities and that he knew:

"*...other people have been put off doing it by lack of expertise and information on plumbers*" (Transcript 3)

He also commented that it:

"*...doesn't help other businesses when they're trying to consider these things*"

Additionally, problems had arisen where the experts drafted in to do sustainability or feasibility assessments that included consideration of RWH and were not familiar enough with the tools and techniques to provide a fully competent assessment. This was exemplified in one particular case where the supply-demand balance for a RWH system could not be calculated, as the assessor did not know how to quantify the potential non-potable water demand of a commercial kitchen.

In the case of advice, it was observed as well as reported by the interviewees that limited advice was available regarding all stages of the implementation process. During each stage of the process, interviewees commented on events that orientated around the provision, or lack there of, of advice. In relation to initial information and system design, one interviewee did not know where to go to ask advice about water efficiency and RWH. They openly and without prompting reported feeling reluctant in approaching the local water company. The interviewee did not think they would help, due to the fact their business paid the water company for a service (i.e. the provision of water) and it did not make sense for them to be promoting less use of their product:

"*As it's not really in their interests, we'd be paying them less – seemed illogical*" (Transcript 7)

In contrast, another interviewee reported getting excellent help from the water company on water efficiency suppliers:

"*We went to them for information as they seemed the natural place to seek information on water*" (Transcript 3)

Thus both interviewees were motivated to seek advice regarding RWH, but had different views on where to source that advice - neither was exactly sure as from where to obtain advice. With regard to recent promotional material on RWH, interviewees were asked if they had seen the leaflet on RWH for SMEs (EN896) published by Envirowise (2008). Surprisingly, no one had seen the leaflet, but even more surprisingly no one had heard of Envirowise and consequentially did not associate them with a source of advice on RWH or general water. Two interviewees commented further, one to say that the leaflet looked interesting as an introduction to RWH and the other that:

"*…needs to be with a water bill or something*" (Transcript 3)

As opposed to them having to find it for themselves.

Further to this, two more specific issues regarding advice were raised. The first was that there seemed to be a lack of *local* advice. One interviewee was reluctant to bring in someone from any distance away due to the potential cost implications of their time i.e. that in having a meeting with someone they would effectively be paying for their travel time, rather than or in addition to any consultation time. This was highlighted as especially important to small SMEs, where margins were perceived as notably smaller with less room for maneuver financially. The second was that five out of the seven interviewees were not given any advice on the maintenance commitment required for the systems that had been considered or installed - either at the design stage or post-installation. For the cases where a system was installed, they were simply left to reactively and adhocly deal with anything that arose. The requirement for proactive, regular and scheduled maintenance was not made apparent by any of the implementing parties in these cases. In each of these cases a major issue arose, which could have been easily prevented by the provision of advice (and guidance, but this will be described separately).

For the other two interviewees, the situation was slightly different. In one case the system was designed, installed and maintenance provided in-house by an individual with personal expertise in plumbing and RWH. In this case no problems were experienced and the individual had sought out as much advice on proactive maintenance as possible. In the other case, advice on and a maintenance contract was provided by the system supplier, but issues still arose. Primarily this was due to the interviewee having their own maintenance staff. As such a contract for provision had to be negotiated between the two parties to cover all requirements, but ensuring that the supplier provided enough cover for the warrantee on the equipment to still be valid. Whilst the contract was being negotiated neither party conducted maintenance activities due to the disputed 'ownership' of each activity during that period.

Further problems arose due to the locality of the contracted maintenance service provider. As is sensible in any small business, the provider grouped maintenance visits by area, to reduce both travel and labour costs. However, between scheduled visits faults arose in the system's operation and the 'local' maintenance team did not have enough expertise to diagnose the problem. When asked for advice, the contracted maintenance provider responded that they would deal with the problem when a scheduled visit to the area occurred - meaning that the system was non-functional for the intervening period, consequentially using mains water rather than RW. For one particular fault, this could have been highly detrimental to the system, as the problem involved the system pumping against a closed valve. Left unresolved this had the potential to cause the pump to break completely, resulting in an expensive replacement being necessitated. This highlights that even where contracted maintenance provision is in place, difficulties with access to advice locally can result in a significant post-implementation system operation deficit.

4.4.1.1 Responses and Recommendations

Several suggestions were made by interviewees as to how to improve the situation regarding expertise and advice. Firstly, the suggestion was made that there should be a registered list of qualified installers for each area of the country, such as existed for renewable energy installers. Additionally, it was identified that the use of appropriate tools during feasibility assessments was limited. As such, it would be recommended that both equipment suppliers and installers should be made aware of and trained in the use of tools endorsed by appropriate bodies.

Coincidentally, during 2009 a consultation on Part G of the Building Regulations was undertaken, to include water efficiency. As a result of the consultation, several changes to Part G were announced. Among these were the introduction of a competent persons scheme for the supply of wholesome water and the supply of non-wholesome water to sanitary conveniences and a water efficiency calculator for new dwellings (DCLG, 2009a). These were due to come into effect on the 1st of October 2009, but were postponed until April 2010 (DCLG, 2009b). Additionally, a new British Standard (BS 8515:2009) was released during 2009, which should help to improve the quality of RWH system designs and installations.

In theory, based on the interview findings, such measures should help fill the current gap in expertise and advice, with experts being more technically aware and certificated. If suitably promoted and enforced these schemes have the potential to encourage installers to undertake additional training, which will in turn help decrease the confidence deficit identified and increase the credibility of suppliers and installers. However, this depends on the accessibility of training, in terms of both cost and availability of places. Greater recognition of and dissemination of information/guidance on post-installation requirements, such as maintenance, by installers is also required and could easily be facilitated under the remit of such schemes.

4.4.2 Guidance and Support (G&S)

Several issues relating to guidance and support arose, throughout the stages of the implementation process, with it being described by many of the interviewees as complicated, stressful and time consuming. Overall:

"*No specific support was identified*" (Transcript 1)

And the common feeling was that it would undoubtedly have been good to have a dedicated support organisation. In relation to the first stage, feasibility assessment and design, it became apparent that interviewees did not receive any clear guidance on how to undertake feasibility assessments or how to engage someone in doing this on their behalf. This particularly frustrated one interviewee:

"*I think whoever promotes this sort of thing needs to have an independent person to come and tell me 'this is what you need to do, it will cost X', then it would make things easier. Then you could make a decision*" (Transcript 6)

It was also observed that there was limited guidance on non-technical aspects, such as the implementation process itself i.e. the sequence of events, how they happened and potential pitfalls, as well as support in maintaining momentum throughout the initial stages of decision-making. In one case it was reported that conversations drove the project, rather than a clearly defined plan or schedule that had been devised in association with supposed guiding parties (i.e. those parties being contracted by the SME):

"*Conversations drove the project. [Name] ordered parts and gave them to [name] the plumber, who was left to figure things out.*" (Transcript 1)

Two stakeholders were regularly flagged up as providing a guiding and supporting role, those being SWW and EnVision (the South West environmental support programme helping businesses to save money and develop new green markets). Neither of these is specifically tasked with promoting or enabling SMEs to consider RWH (and the latter water in general). As such there was a common feeling that they were as supportive as they could be:

"[SWW] gave information on water efficient goods and advice on suppliers" (Transcript 3)

But neither had the inclination or resources to provide the full level of support the interviewees felt was required in relation to the practical and contractual requirements that arose.

In two cases interviewees felt particularly unsupported by local planning departments, where planning permission in relation to RWH installations was required. In these cases interviewees viewed the planners as inflexible, not looking at the whole picture and not recognising the contribution RWH could make in the context of local water resources. They were also seen as reactive rather than proactive, as they were not well informed about RWH and as such delayed the implementation process whilst they undertook investigations and determined how planning rules should be applied:

"*Planning were horrendous – put me off doing it quite frankly*" (Transcript 6)

An absence of dedicated project management and the assignment of unilateral project managers also meant that the installation part of process did not run smoothly, as resolution of any issues were dealt with during spare time. In general this deficit was attributed to a lack of resources to fund such a role (this will be discussed more fully under the 'Finance and Consultation' deficit section). In such cases interviewees felt that there was a real reluctance on the part of the diverse range of installation parties, to provide more guidance and support than absolutely necessary:

"*[there were] no local companies we could mull things over with*" (Transcript 5)

However, even where dedicated project management was present, as the result of the RWH being part of a large-scale construction project, the RWH installation crossed many levels of responsibility i.e. building construction, mechanical and electrical installation, plumbing and health and safety. As a result there was a lack of ownership regarding who provided what support at what time and to what extent. The main problem in this case was a lack of clear accountability and no definitive guidance to determine who should assume overall responsibility for the implementation:

"*...reluctance to take ownership of problems that arose.*" (Transcript 4)

Clearly from the number of problems and faults that arose (in all cases of implementation), there was a significant deficit in post-installation guidance and support. This observation was echoed in comments from several interviewees, including:

"*Post-installation process/support is non-existent – there needs to be more support as a lot of people have been burnt*" (Transcript 5)

The sentiment behind this comment centred on problem-fixing and bad workmanship and there not being enough assistance in helping resolve such issues. It was identified that some mentoring sessions were provided by a local sustainability grant scheme, which covered items such as RWH and renewable energy. However such sessions were limited and again interviewees felt that support was underprovided. The overall feeling regarding guidance and support was summed up by one interviewee in saying:

"*The system is not well organised enough to support everything and you're left to sort it out*" (Transcript 5)

4.4.2.1 Responses and Recommendations

Interviewees suggested that a more clearly defined, independent and central source of advice, information, guidance and support would have been particularly helpful. Hours of internet searching yielded no single point of contact and they were not sure of the most appropriate organisation to approach. As such it is recommended that a body, whether existing or newly appointed, should be charged with responsibility for promoting *and* supporting SMEs (and potentially other stakeholders) in implementing

RWH. For example, the organisation could be responsible for coordinating all guides, manuals, tools, regulations, standards, policies, relevant funding schemes and databases, such as the competent persons list initiated under Part G of the Building Regulations and of suitable demonstration sites (a 'buddy database' was suggested by one interviewee). It could also provide mentoring sessions and specific guidance on the implementation process. No indications were given as to what sort of organisation would be more credible in providing such a role (e.g. Government department, NGO etc), although planners were seen as particularly unhelpful.

Placing responsibility of such a scheme within the planning forum would have benefits, however, as building control departments are already charged with enforcing adherence to Building Regulations. Alternatively, the EA is responsible for water resources management and therefore could perhaps assume such a role. However, further research would be required to clarify whom stakeholders would regard as suitable/credible. As the interviewees main source of information was the internet, from the evidence gathered and suggestions made, promotion of such an organisation/scheme could be undertaken by placing a website address on water company bills, local council department lists, on water efficiency promotional material and other related forums. Clear guidance and support by Government, in terms of policy and promotion, would also be required to ensure central coordination of outcomes.

4.4.3 Confidence and Communication (C&C)

As briefly mentioned in the 'Expertise and Advice' and 'Guidance and Support' sections, there was a divergence in self-belief and confidence between and within the interview groups. Some believed they had or did have the in-house skills to undertake the entire implementation process themselves, while others were not so comfortable with such an undertaking or even in sourcing the right information. In some cases there was a feeling that the process was being made up as it went along:

"*Would have undoubtedly been good to have a support organisation to go to – we were making it up as we went along*" (Transcript 1)

Inadequate communication between parties involved in aspects of implementation certainly did not help. Limited communication between pre, during and post-implementation parties led to confusion and consequently delays and de-motivation:

"*...sometimes the information wasn't with or relayed to the appropriate organisation or individual*." (Transcript 4)

"*Constantly battling the 'it's not our responsibility' mentality"*" (Transcript 4)

Technical information, as well as descriptions of problems and their solutions, were often not relayed to the party most appropriately qualified to address it. In two cases, the interviewees were considering RWH as part of works funded by a general sustainability scheme grant. However, they did not know (were not directly informed) if a water audit of their property had been done to assess the feasibility of a RWH for their business.

"*I don't know 100% if we did or not – wasn't told as such*" (Transcript 5)

This potentially points to a lack of communication between those brought in to operationalise the grant scheme and the party they are aiming to assist.

One particular deficit in confidence and communication was identified as a suspicion of and distrust in equipment suppliers and their data (or lack there of). This arose as the suppliers were unable to communicate to the interviewees in a feasible way how they would benefit from RWH. They were not seen as independent or credible, due to trying to sell various pumps, tanks etc and as such were treated with caution and scepticism. One interviewee stated that there is:

"*Not enough confidence or expertise – some companies don't give a monkeys*" (Transcript 5)

In addition they felt that things could be improved by having an increased confidence in the process/system. In this context the 'system' was taken to mean the overall support framework for RWH implementation, rather than an actual RWH system:

"*...one party with overall responsibility for the entire system should have been agreed from the beginning*." (Transcript 4)

In terms of installation, there were many complaints and it was apparent that confidence in the 'experts' decreased after implementation commenced, things started to go wrong and could not be or took long periods to be resolved. In one case the lack of confidence generated was so great it meant that:

"*The management are also reluctant to fit RWH anywhere else on the site (or other sites) as it's seen as a failure*" (Transcript 2)

Thus a real lack of confidence in workmanship was being generated. This was also true in non-implementing cases, where interviewees had suffered bad prior experiences with other system implementations or renovations. They were already assuming a position of low confidence and were almost pre-emptive that there would be problems:

"*We rebuilt rather than renovated one of the buildings…basically we overspent…it was all so stressful I decided doing RWH at the same time was too much hassle.*" (Transcript 6)

Thus they were therefore less likely to consider installing RWH if they were not confident and were worried about the potential financial implications of bad work i.e. paying for remedial work, as well as being a lengthy and complicated process to endure. In certain cases there was a real anxiety about finding someone they could trust to undertake the work.

A further contributing factor to the lack of confidence in RWH, was frustration stemming from not being able to see a fully operational RWH system in a similar sized business property. Three interviewees said this would be useful in allowing them to see how the systems were performing and had performed since being completed. They were also keen that such systems would be relatively local, so that they did not have to allocate a lot of time or resources to visiting them:

"*Might make sense to see one – wouldn't want to travel far, be nice if they were hospitable. Though I would want it to have been there for about 5 years to see the pitfalls and benefits*" (Transcript 6)

Details of such projects could easily be communicated as part of an overall strategy on making already implemented systems more visible. This will be covered in more detail in the 'Visibility and Access' section.

In summary, conflicts of communication, ownership, accountability and willingness to accept responsibility for problems on the part of the planning or installing parties were common. These manifested themselves in the interviewees as an overall lack of confidence in both the supply of equipment, the process of implementation and in the technology of RWH itself.

4.4.3.1 Responses and Recommendations

Frustration with post-installation fault-ownership issues decreased the interviewee's confidence in RWH. As such, provision should be made from the start of a project, as to the accountabilities of each party involved in the implementation. A model agreement for scheduling maintenance activity was published by Shaffer *et al.* (2004), which could be easily adapted for such a purpose. However, this document was not used in any of the implementations observed and thus awareness of and accessibility to such documents needs to be improved if they are to be used effectively. This would perhaps facilitate a better culture of communication between the parties, as they would be incentivised (by being accountable) to ensure that their part of the implementation handed over properly to the next party.

As previously mentioned a new standard in relation to the installation of RWH system was introduced in 2009 and amendments to Part G of the Building Regulations are due to come into effect in April 2010. Measures such as the competent persons list should help to improve the confidence of stakeholders, as implementer confidence would be increased by greater training and knowledge provision.

4.4.4 Visibility and Access (V&A)

Throughout the interviews, visibility of and access to a range of resources were highlighted both directly and indirectly as being very limited. These can be roughly broken into the following areas:

- Promotion - who is promoting RWH and how;
- Guidance - on how/where to find information;
- Information - actual guides, manuals, tools;
- Expertise and equipment - manufacturers, suppliers, tradesmen, plumbers;
- Demonstration systems - test cases, operational systems.

Initial investigations and information searching were conducted using the internet in six out of seven occasions:

"*...did a lot of research using Google etc*" (Transcript 7)

In the other case the interviewee was not the main person responsible for the implementation and as such did not know how initial information searching activities were performed. Internet searching also formed the primary source of information as implementers were going through the process (i.e. for trouble shooting). Information was identified, but the searching was seen as labour intensive and in several cases resources were not available to search further and so the interviewees got frustrated and discontinued their searching:

"*We didn't have time to find out where the right people were*" (Transcript 6)

Insights were also gained from what the interviewees did not say. For example, they did not identify any specific support - none mentioned finding a dedicated source of information and most of the organisations promoting RWH were simply not 'visible' to them. They simply did not know which was the most appropriate place/organisation:

"*Hadn't really thought about asking SWW as we pay their bill – didn't really think they would be happy to help us reduce our consumption*" (Transcript 7)

Thus the visibility of organisations promoting RWH and providing guidance would appear to be very limited. In addition, access to the guidance and information they provide is also limited. Although the EA produce a guide on RWH (EA, 2008b), none of the interviewees mentioned having seen it, or even mentioned the EA as a potential source of information, support or guidance. This was also the case for Envirowise, which released a leaflet on SMEs and RWH (EN896) before the interviews were undertaken. Although the interviewees had been through the process or considered RWH prior to the release of the Envirowise leaflet, they were asked as to whether they had seen it. As a result, they would not have seen Envirowise as the natural place to seek guidance or information on RWH. Therefore the interviewees were left to use their judgement as to whether a source of information or guidance was trustworthy.

Knowing where to find qualified and trustworthy tradesmen was also a key area that concerned interviewees. One interviewee suggested it would be useful to have an:

"*Approved contractors list for areas – such as you can get for renewables*" (Transcript 5)

As previously mentioned (Section 4.4.1.1), this is actually due to be implemented in 2010. Whether it becomes 'visible' to those who need it is a matter for time to tell. It was also apparent from the problems identified and the lack of information provided to the interviewees during installation, that some of the installers were not necessarily using or perhaps aware of the appropriate guides, manuals and tools. For example, Shaffer *et al.*'s (2004) document on how to prepare and implement a schedule for maintenance provision (CIRIA report C626) was not mentioned or recommended to the interviewees by the installers. Had the interviewees been made aware of this document, or had the installers used it to assist the interviewees in implementing a maintenance schedule, they may have been more informed about maintenance and issues arising as a result of a lack of maintenance been avoided:

"*…no one mentioned regular maintenance during the installation and we don't have a schedule or documents for it – we do it as and when we think it needs doing.*" (Transcript 2)

It could be argued that provision of such guidance is not within the remit of the installers, however, the visibility of and access to such documents should be enhanced to prevent future installations falling foul of the same issues.

Finally, unprompted, three interviewees complained that they did not know where to go to see systems in action i.e. test cases or demonstration sites. Both expressed an interest in seeing how SMEs of a similar size/demand to them with a RWH found the system, in terms of operation and performance. One went on further to suggest:

"*Perhaps a 'buddy' system – mentors on a database, similar sized businesses who already have done it and can guide others, like demonstration sites that are actually functioning and monitored businesses, so you can see how it operated and how they benefit*" (Transcript 3)

4.4.4.1 Responses and Recommendations

In enabling SMEs (and indeed, other stakeholders) to consider and implement RWH, both visibility of and access to information, advice, guidance and support are crucial. Based on the evidence gathered and suggestions made, this would best be provided by a single, central, independent source of information and guidance. This would prevent conflicts of responsibility or inadequate resources from obscuring the visibility and restricting the access. Providing a central website address would also enhance the visibility and access of such support, as confusion would be reduced regarding which organisation to approach. Enhancing visibility of and access to facilities such as a 'buddy database' and a list of approved installers, would increase the direct guidance and support available to SMEs. Such a facility would reduce the resource expenditure of the SME in identifying information and would therefore also perhaps make consideration of RWH more attractive.

4.4.5 Finance and Consultation (F&C)

In all but one case, assessing the potential financial savings provided by a RWH system was a key factor in considering undertaking an installation. In this case sustainability drivers were primary, rather than financial ones. In the other cases saving money on water bills by undertaking water efficiency activities was the primary driver for considering RWH, although sustainability and avoiding waste were also strong drivers:

"*Financial reasons – current water bill is £17,000 – this could be vastly reduced as majority of uses do not require potable level quality*" (Transcript 7)

RWH was initially included on the plans for two interviewees who were expanding their premises. However, in both cases funding shortfalls (one via a sustainability grant, the other from a Section 106 agreement) meant that one system was taken off the plans and the other was revised back - resulting in only the main underground tank being installed:

"*No funding to purchase equipment or install it – currently hastily trying to seek funding*" (Transcript 7)

For the former, the interviewee explained that the level of the sustainability grant applied for, would only meet 20-40% of the costs of the measures that were planned to be implemented, which was simply not adequate. Furthermore, they also reported that the dates within which the measures had to be implemented were far too restrictive. Had adequate consultation been undertaken during or after the implementation of the sustainability funding scheme, the needs of the interviewees may have been more adequately identified and lessons learnt for future schemes.

For the latter case the idea was to fit the rest of the RWH system equipment (pump, header tank etc) as and when funds became available. This staged implementation was eventually completed; however, delays and problems necessitated remedial work. These cases exemplify that where capital funding deficits occur, or identified funding is inadequate, the quality of installation is compromised or the installation does not go ahead. In this latter case the interviewee commented that:

"*Having enough funding upfront may have made things run more smoothly*" (Transcript 1)

In a third case, where the interviewee was also planning to expand premises, RWH was included within plans, but again funding to purchase equipment and install it was not available. In this case the interviewee had undertaken a very detailed feasibility assessment and had a high level of in house knowledge. The main deficit was in funding, which they were desperately trying to secure, so that the RWH would not have to be taken off the plans. In this case planning permission had been secured and construction had begun. Construction was being delayed as they were aware that implementing a RWH system within a new build was more straight forward and less costly than retrofitting after construction was completed. They were trying to find and apply for sustainability-orientated grants, within which RWH was an approved technology. They were very frustrated that funding mechanisms were generally inadequate and not transparent, as they knew what they needed to do but simply did not have the funds to do it. They had not heard of the ECA and when informed about it, reported that they would look into it, but did not have much confidence that it would be adequate enough:

"*…trying to find grants to apply for which cover that sort of thing [RWH]*" (Transcript 7)

This sentiment was echoed by another interviewee who had completed an implementation and considered claiming back the ECA. It was reported that the amount claimed back would be negated by the fee required for an accountant to submit the claim. As the process involved claiming tax back, the interviewee viewed this as complicated and did not feel confident enough to go through the process themselves and thus required the accountant. In this case this was compounded by costs associated with retrospective planning permission, which added to the pay back period and therefore reduced the cost-benefit of the system for the interviewee:

"*We did know about ECA…the increase in accountants charges would wipe out any gain.*" (Transcript 3)

Further financial concerns were expressed with regard to poor workmanship and in commissioning feasibility assessments. In several cases system faults occurred due to poor workmanship during installation. The interviewees were not happy that they had to foot the bill for this and any remedial work themselves, especially where work should have been covered under a warrantee, but fault ownership conflicts resulted in them having to rectify matters themselves. Resolving such issues was costly, both financially and in terms of time and stress. In terms of feasibility assessments, one interviewee had previously undertaken one for a borehole, at a cost of several hundred pounds. It was subsequently ascertained that a borehole was not feasible and they were not happy that they had effectively wasted their businesses' money. They were reluctant to commission another assessment for RWH, due to the possibility that it again might not be feasible and they would 'loose' more money:

"*Spent £500 to find out that it wasn't feasible.*" (Transcript 6)

Finally, several interviewees reported that it was the 'invisibles' (implying things they had learnt about after implementation, such as remedial work and maintenance), that added up and had an effect on the cost effectivity of the project. Such costs had not been considered and thus no contingency funds were available. For example, one interviewee leased land from a rail related company and as such they would have had to ensure any works relating to the RWH system were fully secured and low risk to the third party. In this case this involved construction of a security compound around an above ground tank, as an underground tank was not feasible due to the type of land the premise was situated on. Needless to say this externality affected the cost-benefit analysis and the RWH system was not considered further. Thus it was not necessarily just capital costs that were seen as problematic in sourcing for the interviewees, but also funds associated with peripherals, as well as 'risk' factors, such as remedial work:

"*[name] would have required any above ground storage to be fully lockable…thus increasing the costs.*" (Transcript 5)

4.4.5.1 Responses and Recommendations

It has previously been identified (Chapter 2) that there are currently no plans for furthering the financial support available for implementing RWH (whether to SMEs, householders or other stakeholders). The author would argue that before this position is reaffirmed, that consultation of SMEs (and perhaps other stakeholders) should be undertaken, to ascertain what would be most relevant and critical to them in terms of financial support.

If the provision of direct grants or subsidies is not forthcoming, additional measures should be undertaken to support SMEs in applying for existing funds, such as the ECAs. Currently arrangements for claiming the tax on capital expenditure back under the ECA scheme are inadequate for smaller SMEs. For example, often there is not enough expertise present to confidently apply for them, or the financial recompense is less than hiring an expert to apply for the ECA. Greater transparency in how to apply and what is covered by the process is also required. It is possible to claim back capital on installation works, as well as equipment, such as in retrofitting. However, the author wrote to the scheme to find out which types of work were covered. The enquiry was subsequently passed to two interim bodies (AEA Technology and HMRC) and the author was eventually advised that:

"*Your tax office is best qualified to answer your question….You need to tell the [tax] office exactly what works have been done and why any alterations were necessary to accommodate the rainwater harvesting system*" (Williams, 2009)

As such, businesses would have to firstly write to their tax office explaining the works to be undertaken, to identify if they are covered. After carrying out the works they would then have to retrospectively apply for tax back on any works done. As with all projects, modifications may occur which could potentially change their eligibility and they may find themselves not being able to claim the full original amount. Such a convoluted way of receiving money off a system is not only likely to put people off, but also there is the potential for the cost to be in excess of that planned, which as previously mentioned made the interviewed SMEs particularly uncomfortable.

In addition to the ECA, it might also be pertinent for funding non-specific to RWH, but that could apply to RWH, to be identified and disseminated to SMEs (perhaps via the independent body outlined in Section 4.4.2). For example, several interviewees had applied for sustainability grants as an indirect way to fund their RWH system implementations. However, even where the interviewees had done this they struggled to find other sources of funding. Increasing the visibility of and access to such indirect funds would not only help to boost SME financial confidence in considering RWH, but centralising such information would help individual SMEs save resources in searching for such schemes. This could also be extended to cover funding that would apply to feasibility assessments, so that SMEs would not feel they were making a loss right from the start. Alternatively RWH-specific funding could be made available for such assessments; it would not be funding RWH directly per se, but would be helping to enable SMEs to consider RWH as a viable option in which to invest. Any such funding should also be flexible in terms of date of application, once granted, in order for SMEs to not feel restricted by the support that they are receiving.

4.4.6 Construct Validity of the IDCs

As the study was not aiming to achieve a 'cause and effect' within the interviewees, internal validity was not considered. However, in interpreting the interview transcripts it was important to check for counter instances and to ensure that face and/or construct validity were maintained. Face validity is an intuitive check as to whether results seem reasonable (Robson, 2002). Construct validity ensures that the method undertaken actually measures what it set out to measure. In re-examining the transcripts consistency in the occurrence of each IDC was achieved, with a large proportion of the text coded to one, or more, IDC. Robson (2002) and King (2004) caution against using the frequency of occurrence of codes within text, warning that frequency does not necessarily relate to prominence. Despite these recommendations, it was decided to use the quantitative functionalities of NVivo to determine the percentage of the interview content coded to each IDC. The total percentage of content for each IDC was also calculated, as was the mean percentage of content for implementers and non-implementers separately. These are summarised in Table 4.3 for each interview transcript.

Table 4.3 Percentage of content allocated to each Implementation Deficit Category (and 'other' categories) within the 7 interviews

Interview Transcript	E&A	G&S	F&C	V&A	C&C	Other (drivers etc)	Uncoded ('normal text')
1 (I)	48.32	18.1	7.63	2.95	1.48	2.95	18.57
2 (I)	69.85	14.15	1.78	2.98	8.83	2.41	0
3 (I)	19.18	32.99	14.08	12.47	4.53	5.95	10.8
4 (I)	39.17	26.09	0	4.17	10.26	7.86	12.45
5 (N)	21.32	40.41	10.85	6.01	12.84	5.57	3
6 (N)	11.66	27	21.77	12.03	14.24	8.49	4.81
7 (N)	27.46	11.23	30.93	2.99	1.09	5.37	20.93
Overall Mean	34	24	12	6	8	6	10
Implementer Mean	44.13	22.83	5.87	5.64	6.28	4.79	10.46
Non-implementer Mean	20.15	26.21	21.18	7.01	9.39	6.48	9.58

E&A = expertise and Advice; G&S = guidance and support; F&C = finance and consultation; V&A = visibility and access; C&C = confidence and communication

By summing the means of percentages for the 5 ICDs, it was calculated that overall, 84% of the interview content could be coded to the IDCs, which could be considered to represent a high construct validity. Only 16% was accounted for by other items, such as mention of the drivers motivating the interviewees to consider RWH, as well as unrelated text present in normal conversations. Oppenheim (2005) warns against heavily quantifying small numbers of interviews, as they may not be properly representative of a population. As such, the interviews provide a general indication of IDCs relevant to SMEs, not data on how often they are likely to occur within a population. However, three categories seem to dominate the content; 'Expertise and Advice', 'Guidance and Support' and 'Finance and Consultation' categories. Additionally, these seemed to assume different priorities for implementers and non-implementers. It was decided to therefore explore these differences further to see if they assumed any quantifiable significance.

4.4.7 Implementer and Non-implementer Differences

As would be expected there is a difference in the percentage of content of each IDC within each interview. For example, for interviews 1 and 2 E&A percentages of content were highest. In contrast, for interviews 3 and 5 G&S had the highest percentage of content, whereas for interview 7 it was F&C. As such it was decided to investigate whether there was an observable difference in the percentage of content of the IDCs between those that had been through the implementation process and those that had not. In charting the mean percentage of content of implementers and non-implementers (Figure 4.2), it was identified there appear to be differences between the two groups, with E&A having a higher percentage of content for implementers and F&C having a higher percentage of content for non-implementers. In order to determine if the observed differences are indeed significant, inferential statistical analyses would usually be undertaken. Due to the small sample of interviewees within the present study, such analyses would not be appropriate.

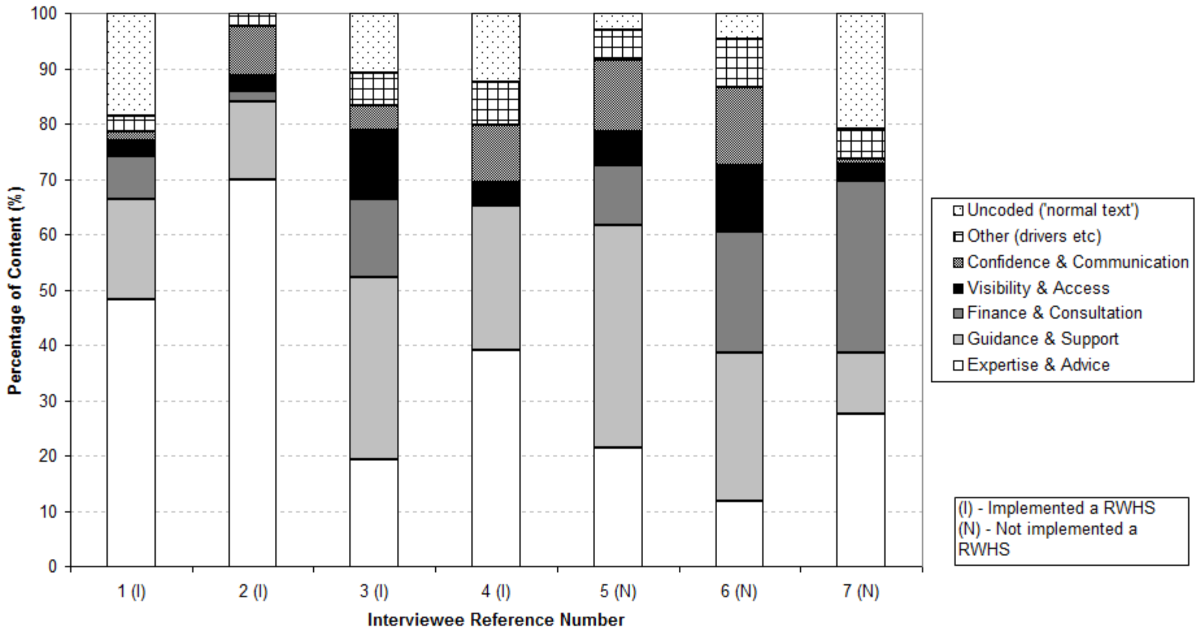


Figure 4.2 Variation in Percentage of Content within each Interview for the 5 IDCs for Implementers (I) and Non-Implementers (N)

4.5 Chapter Summary and Key Messages

This chapter has presented the results of interviews conducted with SMEs in the South West of England, some of which had been through the process of implementing RWH and others who had considered implementing RWH, but were unsuccessful for a number of reasons.

In answering the research questions posed at the beginning of the chapter, it was identified that:

- The primary source of information used is the internet, followed by third party advisors who are not necessarily experts in or experienced with RWH;
- Although there are finance schemes available to SMEs they are considered inadequate and difficult to access;
- There are a number of obstacles discouraging SMEs from implementing RWH, which have been summarised into five IDCs:

1) Expertise and Advice (E&A);
2) Guidance and Support (G&S);

3) Visibility and Access (V&A);
4) Confidence and Communication (C&C);
5) Finance and Consultation (F&C).

- Overall, the implementation process proved to be frustrating, time consuming and the level of support given by third parties reduced SME confidence in RWH.

Overall, E&A, F&C and G&S were the most prominent, although there were differences between interviewees at different stages of the implementation process. From the discussion undertaken, it can be concluded that reducing the IDCs requires assistance that goes deeper than purely the provision of information or distanced guidance. If SMEs are to be fully enabled in considering and implementing RWH, both policy and support services will need to undergo considerable changes. The key messages resulting from the interviews are:

(1) Visibility of and access to a list of qualified installers is required (such as that due in 2010 under changes to Part G of the Building Regulations);

(2) Increased training is required for designers/installers to increase implementer confidence and to support the above scheme;

(3) A central, independent body responsible for coordinating all resources (information, manuals, funding) relating to RWH needs to be established, whether that being a new body or the widening of the remit of an existing body;

(4) Increased transparency of the ECA application process is required, especially in relation to retrofitting, as well as identification and dissemination of information on other indirect funding/subsidy schemes applicable to RWH.

This chapter and the previous chapter have identified that although the receptivity of the stakeholder groups investigated is high, there are a number of support and technical issues that undermine their ability to implement. The following two chapters explore some of the more technically-orientated issues in order develop the technical evidence base and to make recommendations for these within the overall strategic framework developed in Chapter 7.

5 CHAPTER 5: UNDERSTANDING RWH SYSTEM PERFORMANCE - WATER QUALITY ASSESSMENT

5.1 Introduction

Objective three of the thesis is to enrich the technical (and social) knowledge base relating to RWH in the UK. Chapter 2 and Chapter 3 highlighted that there are possible concerns regarding health and safety issues in relation to RWH. Chapter 2 also identified that certain physicochemical parameters can have implications for RWH system function. Consequently, the following technically-orientated research questions were identified, which are addressed in this chapter:

- What impact do physicochemical parameters have on RWH system function?
- What is the health risk associated with flushing WCs with RWH?

An office-based RWH system was chosen as a case study to examine this research question for a number of reasons. Firstly, the majority of research conducted on RWH systems in the UK has been at the household scale or for large combined rainwater and greywater systems, as identified in Chapter 2. In contrast to this, limited analysis of harvested rainwater quality from medium scale commercial systems has been undertaken. Additionally, the greatest opportunity to implement RWH is arguably within the SME (small to medium enterprise) sector, due to the drivers outlined in Section 2.5.3.1. Finally, a system was being implemented within an office-building on the University of Exeter campus, thus providing an excellent opportunity for a detailed study of harvested rainwater quality.

This chapter is divided into three main sections:

- **Case study and Monitoring Programme;**
- **The Impact of Antecedent Weather Conditions;**
- **Implementing a Health Impact Assessment.**

The first section describes the RWH system that was investigated, along with details of the results of the harvested rainwater quality monitoring programme implemented. The second section examines the results of the first section more extensively in relation to weather data collected in parallel with the monitoring programme. This was undertaken to identify the potential impact of antecedent weather conditions on resultant water quality parameter values. The final section undertakes a health impact assessment, which includes a quantitative microbial risk assessment (QMRA) to determine a microbiological disability affected life year (DALY) score for the system. This utilises the results of the monitoring programme to quantify the health risk associated with flushing WCs using harvested rainwater. Comparators are also given, to place the risk-based results in context. These activities result in the answering of the two research questions for the chapter.

5.2 Case Study and Monitoring Programme

5.2.1 Site Characteristics

The Innovation Centre (IC) on the University of Exeter's Streatham campus is a new-build office building (Figure 3.64, Chapter 3). A RWH system is located within the building and used to flush toilets in order to reduce mains water consumption. The RWH system consists of catchment, conveyance, storage and redistribution sections. The catchment and conveyance section consists of a south-facing roof catchment (1500m ^{2}) that has both aluminium and bitumastic-felt-membrane sections (Figure 5.1) and powder-coated aluminium rainwater goods (guttering and downpipes), (Figure 5.2). The storage and redistribution section consists of a glass-reinforced plastic (GRP) underground storage tank (25m^3), a control system, two GRP header tanks (0.8m^3 each) and associated medium-density-polyethylene (MDPE) and copper pipework. There is also a three-tiered filtration system, consisting of a 440µm pre-tank coarse debris filter, an 180µm in-tank floating suction filter and a 35µm inline backwashing filter. The backwashing filter provides the highest level of filtration for the harvested rainwater, as well as automatically backwashing to prevent clogging and maintain performance. These components are illustrated in Figure 5.3 to Figure 5.6. It should be noted that there is no first flush device fitted to the system, as their use in developed countries is variable. The use of these devices is discussed in Section 2.3.9.1, but it is worth reiterating that they may often be useful in improving the quality of harvested rainwater under certain conditions.

Although there are no trees or vegetation directly overhanging the building, there are large numbers of trees in close proximity (the campus is a registered botanical garden).

These provide perches for over-flying birds. In addition, the site is in close proximity to several car parks, approximately 1km from a large railway station (to the west), less than 6km from a wastewater treatment plant (WWTP) to the south, 10km from Dartmoor National Park (to the north west) and 18km from the south coast.

Figure 5.1 Aluminium and bitumastic-felt sections of the Innovation Centre roof catchment

Figure 5.2 Downpipe and hopper and the main storage tank under the Innovation Centre car park

Figure 5.3 Exterior and Interior of the Innovation Centre RWH system control panel

Figure 5.4 800L GRP header tank and associated pipework (including meters)

Figure 5.5 440µm pre-tank coarse debris and 180µm in-tank floating suction filters

Figure 5.6 35µm inline backwashing filter

5.2.2 Sampling

The layout of the RWH system is illustrated in Figure 5.7. Samples were obtained via a sampling point (6) installed on the copper pipe outlet from the RWH system control panel (5) in the central plant room of the building. This is located between the main storage tank (2) and the header tanks (7). Samples were obtained before the header tanks to rule out the possibility of dilution with mains water from the top-up system. The original sampling point consisted of a standard valve placed on the RWH outlet. However, due to frequent (weekly) use, the valve began to leak and so was replaced with a more substantial and appropriate sampling tap on the 17th of March 2009 (Figure 5.8). The material of construction was the same as the previous valve (copper/brass) and it is therefore unlikely that any impact would have been made on the harvested rainwater quality.

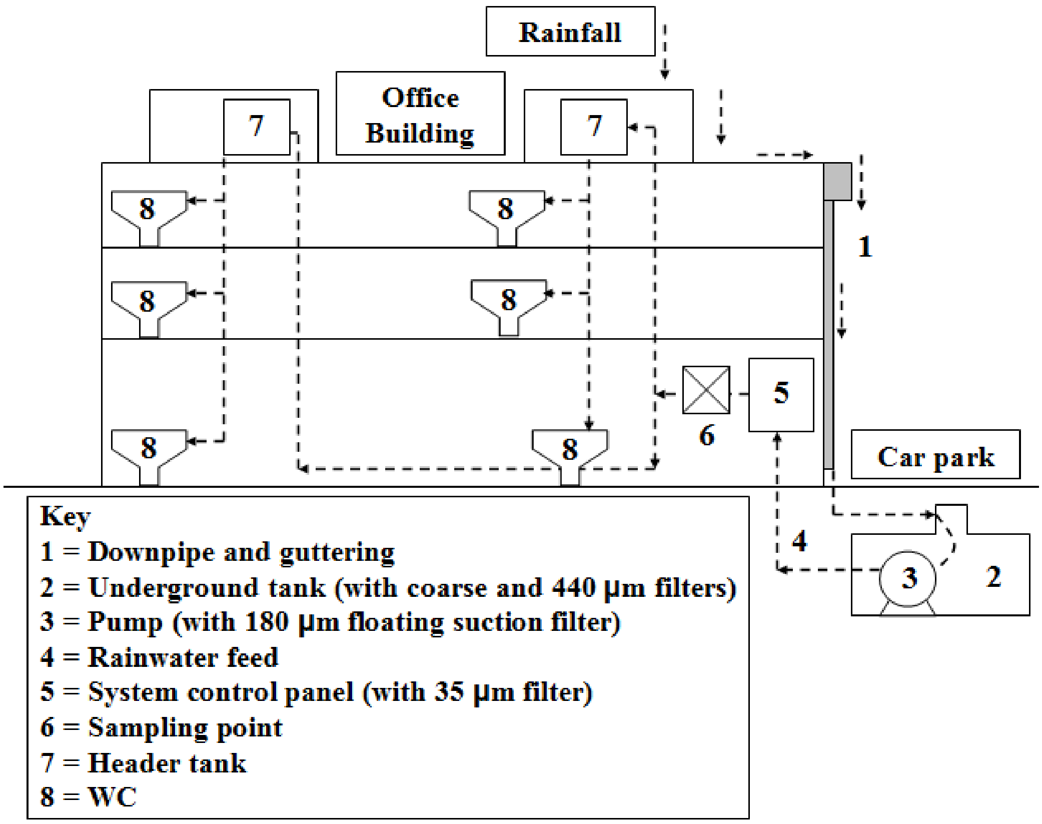


Figure 5.7 Schematic of the RWH system, including sampling point location (6)

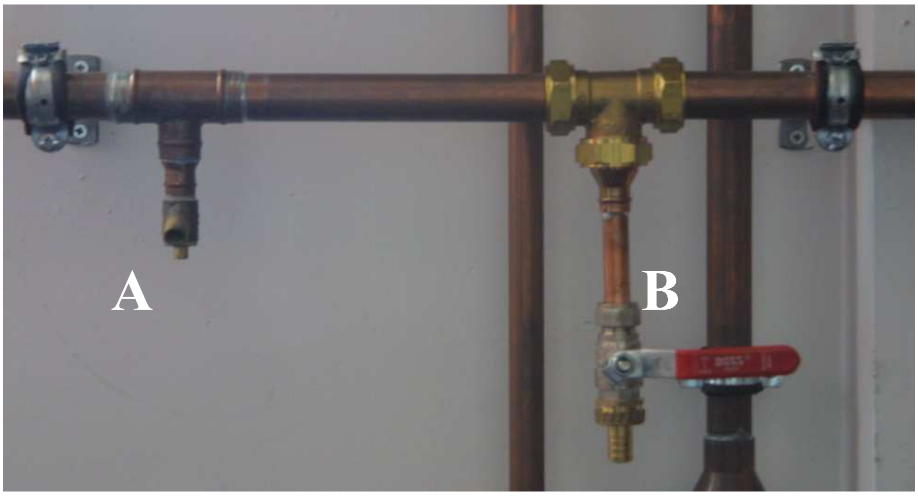


Figure 5.8 Original (A) and replacement (B) sampling apparatus on the RWH outlet

As previously established (Chapter 2, Section 2.3.9), longitudinal (long duration) studies of harvested rainwater quality are particularly sparse for the UK. Therefore it was decided to focus the limited resources available to a longitudinal study of one system, rather than a shorter study of several systems. This was also for logistical reasons – more systems could have been sampled, but this would have resulted in extra collection and transit demands beyond the resources of the project researcher. Several other sampling regimes were considered, for example:

- Sampling from different points across the Innovation Centre system;
- Sampling rainwater before it contacted with the roof material;
- Sampling rainwater after it had travelled through the roof conveyance system;
- Sampling at different heights within the harvested water column of the main storage tank.

However, the primary aim of the study was to identify the temporal changes in harvested rainwater quality to assess implications for both potential long term health effects and system operation. This has the most relevance to the users and maintainers of the system and therefore the longitudinal study had this as its focus.

Information gathered whilst undertaking the literature review of this chapter informed the selection of the parameters that were monitored. However, due to budgetary constraints on sample analyses, the parameters to be investigated and the number of samples were restricted and therefore two sampling regimes were followed:

(i) Weekly collection of rainwater samples – 15 parameters;
(ii) Three-monthly collection of rainwater samples – 41 parameters.

These sampling frequencies were chosen inline with previous studies (CRC, 2005; Jordan *et al.* (2008)). The sampling period ran from August 2008 to August 2009 and in total samples were analysed for 7 microbiological and 34 physicochemical parameters. This extensive range of parameters was used, in order to examine their implications for both health and system function. Additionally, certain physicochemical parameters are known to interact with microbiological parameters and vice versa, therefore requiring as comprehensive an assessment as possible. Overall, 4 three-monthly samples and 42 weekly samples were taken. Due to periods when the system was not functioning correctly or the author was away, there were 11 non-consecutive weeks within the 12 month sampling period when samples could not be taken.

Samples were taken on the same day and at approximately the same time each week. Standard water quality sampling procedure is to flush a sampling point for a period proportional to the diameter and length of pipe prior to sampling (APHA, 2000). Due to the location of the tap (inside a building) this was not feasible (due to the length of hose/number of buckets that would be required to transport the flushed water). Instead, one litre of rainwater was drawn off immediately before samples were obtained. This procedure is inline with that used by Ahmed *et al.* (2008).

In following standard water quality sampling procedures (APHA, 2000), a number of different types of sample bottle were used, depending on the parameter to be analysed in the laboratory. For example, samples for polycyclic aromatic hydrocarbon (PAH) and oil and grease analysis were collected in glass bottles, whereas samples for microbiological and other physicochemical analysis were collected in normal polyurethane (PET) bottles (Figure 5.9). Samples were kept in cool and dark conditions during transit and transported to the laboratory within an hour of being obtained. The samples were pre-registered with and processed in a commercial laboratory using standard methods (APHA, 2000). Details of the standards methods used (such as inductively coupled plasma mass spectrometry (ICP-MS) for metals) are detailed on an example sample results sheet, located in Appendix D.

Figure 5.9 Different types of sample bottle used in the monitoring programme

5.2.3 Weather Data

Initially, weather data was recorded using the Centre for Water System's (CWS) weather station, located approximately 0.5km from the Innovation Centre. Unfortunately due to events beyond the researcher's control, the CWS weather station ceased to function at the end of February 2009 – half way through the sampling period. Another weather station in Whipton, a suburb of Exeter 3.16 km from the CWS, was identified and historic records downloaded for the monitoring period (July 2008 and August 2009; Appendix D). Temperature, precipitation levels and wind speed and direction were recorded at 15 minute intervals and processed as required (this is described in more detail in Section 5.4.1). During the sampling period snow occurred on one occasion (Figure 5.10). De-icing salts applied to surrounding roads during this period (and the entire winter) were identified as having potential implications for the water quality results. These implications are discussed in Section 5.3.1.2.

Figure 5.10 Snow on the Innovation Centre roof (RWH system catchment area)

5.3 Monitoring Programme Results

The water quality sample analysis laboratory results were initially examined using the range; mean and standard deviation statistics (calculated using a standard spreadsheet package). It was identified that greater variability in observed levels occurred for some parameter values, such as coliforms, *Enterococcus faecalis*, nitrogen, chloride, copper and zinc. These observations were used as a starting point for further analysis. Consequently, some parameters are described in greater detail, for example where their variability was high (and the potential significance of this), where they were likely to interact with other parameters or where they were identified as having significant implications for health or system function.

Results for each parameter examined in the study are summarised in Table 5.1 for weekly samples and Table 5.2 for monthly samples. Only a limited range of parameters are included in the previously discussed British Standard for harvested rainwater (BSI, 2009), therefore the WHO (2008) guidelines for drinking water quality are used where the standard does not give guideline values. This is for comparative purposes only, to demonstrate any potential health or function risk posed.

Additionally, although a range of previous studies was identified in the literature review, comparison is not made between the specific parameter value results of these studies and the present study. This is primarily due to the fact that both rainwater and harvested rainwater quality is highly site specific and dependent on a range of factors, including weather variables (such as wind and temperature), type of surroundings (for example, urban or rural) and building and roof construction materials. Appropriate connections between the general trends observed in the present study and those of previous studies are made however, to provide a wider context to the results.

Table 5.1 Summary of the quality of harvested rainwater samples collected weekly

Parameter	Range	Mean	Standard Deviation	Guideline
Total coliforms (no/100ml)	0-2600	173	465	1000[a]
Faecal coliforms (no/100ml)	0-1500	100	290	2000[b]
Enterococcus faecalis (no/100ml)	0-1460	184	301	100[a]
TVC 22°@ 3 days (no/ml)	300-2020000	67266	326139	NI
TVC 37°@ 2 days (no/ml)	5-28000	2717	5161	NI
pH	7-10.4	8.88	1.1	6-8[a]
Conductivity at 20°C (μS/cm)	44-261	93	49	NI
Total Dissolved Solids (mg/l)	30-183	65	35	600[c]
Turbidity (NTU)	0.3-9.7	1.7	1.8	10[a]
Nitrogen as NO_3 (mg/l)	1.4-17.8	5.3	4.2	NI
Ammonium as NH_4 (mg/l)	<0.01-0.6	0.1	0.1	NI
Nitrate as NO_3 (mg/l)	1.3-17.8	5.3	4.1	50[c]
Nitrite as NO_2 (mg/l)	<0.01-0.2	0.08	0.1	3[c]
Chloride as Cl (mg/l)	3-28	7.7	6.2	2[a]
Silicate as SiO_2 (mg/l)	0.35-4	1.3	0.8	NI

TVC = Total Viable Count; a = BSI (2009); b = EC Bathing Water Directive (1975); c = WHO (2008) for *drinking* water; NI = None Identified; NA = not applicable

Table 5.2 Summary of the quality of harvested rainwater samples collected every three months

Parameter	Range	Mean	Standard Deviation	Guideline
Salmonella spp (no/100ml)	0	0	0	0[b]
Cryptosporidium oocyst (no/l)	0-0.1	0.03	0.1	1/1600 [c]
Phosphorus as P (μg/l)	15-50	33.5	19.1	NI
Sulphate as SO_4 (mg/l)	<2.5-5.3	4.4	1.3	NI
Calcium as Ca (mg/l)	5.2-10	7.7	2.6	NI
Magnesium as Mg (mg/l)	0.4-0.6	0.4	0.1	NI
Potassium as K (mg/l)	0.8-2.4	1.4	0.7	NI
Sodium as Na (mg/l)	2.4-4.3	3.5	1	NI
Aluminum as Al (μg/l)	52.3-108	85.4	25	NI
Iron as Fe (μg/l)	9-27.4	17.9	7.7	NI
Manganese as Mn (μg/l)	<2-3.2	3.2	0	400[c]
Copper as Cu (μg/l)	117-290	215.5	72.4	2000[c]
Zinc as Zn (μg/l)	193-480	361.3	120.7	NI
Lead as Pb (μg/l)	1.5-64.4	32.9	26.3	10[c]
Cadmium as Cd (μg/l)	<0.4	NA	NA	3[c]
Chromium as Cr (μg/l)	<0.5	NA	NA	50[c]
Nickel as Ni (μg/l)	<1.5-1.7	1.5	NA	70[c]
BOD_5 (5-day) (mg/l)	<3	NA	NA	NI
COD (mg/l)	<12	NA	NA	NI
Oil and Grease (mg/l)	<1	NA	NA	<0.3[a]
Benzo[a]Pyrene (ng/l)	<1	NA	NA	700[c]
Benzo[b]Fluoranthene (μg/l)	<0.001	NA	NA	NI
Benzo[ghi]Perylene (μg/l)	<0.002	NA	NA	NI
Benzo[k]Fluoranthene (μg/l)	<0.001	NA	NA	NI
Indeno[1 2 3-cd]Pyrene (μg/l)	<0.003	NA	NA	NI
PAHs (Total) (μg/l)	0	NA	NA	NI

a = BSI (2009); b = EC Bathing Water Directive (1975); c = WHO (2008) for *drinking* water; NI = None Identified; NA = not applicable

5.3.1 Physicochemical Parameter Results

Detailed analysis revealed that some physicochemical parameters displayed trends and potential interactions with other parameters. These are discussed in the following sections, along with a brief description of the other results.

5.3.1.1 Nitrogen Results

Nitrogen is a precursor to a number of metabolites (such as nitrate and nitrite), which provide nutrients for biological growth (WHO, 2008). Therefore variability in nitrogen levels could have implications for microbial activity with the RWH system tank. Nitrogen, nitrate, nitrite and ammonium levels were generally low, although two peaks did occur in early December 2008 and late March 2009. pH, conductivity, TDS and silicate also peaked on these occasions. Eckenfelder and Argaman (1991), in the context of municipal wastewater treatment, reported that the optimum pH to minimise the creation of nitrogen and nitrate (from ammonia) is 7 (or less). This is supported by Tyson *et al.* (2007) who identified that as pH increased from 6.5 to 8.5 nitrification (oxidation of ammonia into nitrites then nitrates) rates increased by 1.75 times. It would therefore appear that a low (acidic) pH is beneficial to maintaining a low nitrogen concentration, with an aim to restrict microbial growth. The pH in the present study was consistently high (alkali) and therefore may have resulted in higher nitrogen concentrations.

In order to explore this relationship, the nitrogen and pH data series were compared using linear regression. Figure 5.11 (A) illustrates the relationship between pH and total nitrogen (N), which seems to indicate a weak positive linear correlation. However, there are a number of outlying values (to the top right of the plot), which have the potential to skew subsequent statistical analysis. In line with standard statistical practice (Kinnear and Gray, 2008), these outliers were removed and the data series re-plotted (Figure 5.11 (B)). It is clear from the normalised data that there is no linear correlation between pH and nitrogen concentrations, for this study. This was further confirmed by examining the coefficient of determination (R^2) for the linear regression plots, which is a measure of variability and the likelihood of predicting a data value for one series from a data value of another series (Kinnear and Gray, 2008). An R^2 value of 1 indicates a significant relationship and the significance decreases as values tend towards 0. The values for the two regressions in this study were 0.09 and 0.03, respectively, indicating there was not a significant linear correlation between pH and nitrogen. This indicates, in the context of a RWH system, that an alkali pH does not necessarily lead to higher nitrogen (and therefore nutrient) levels.

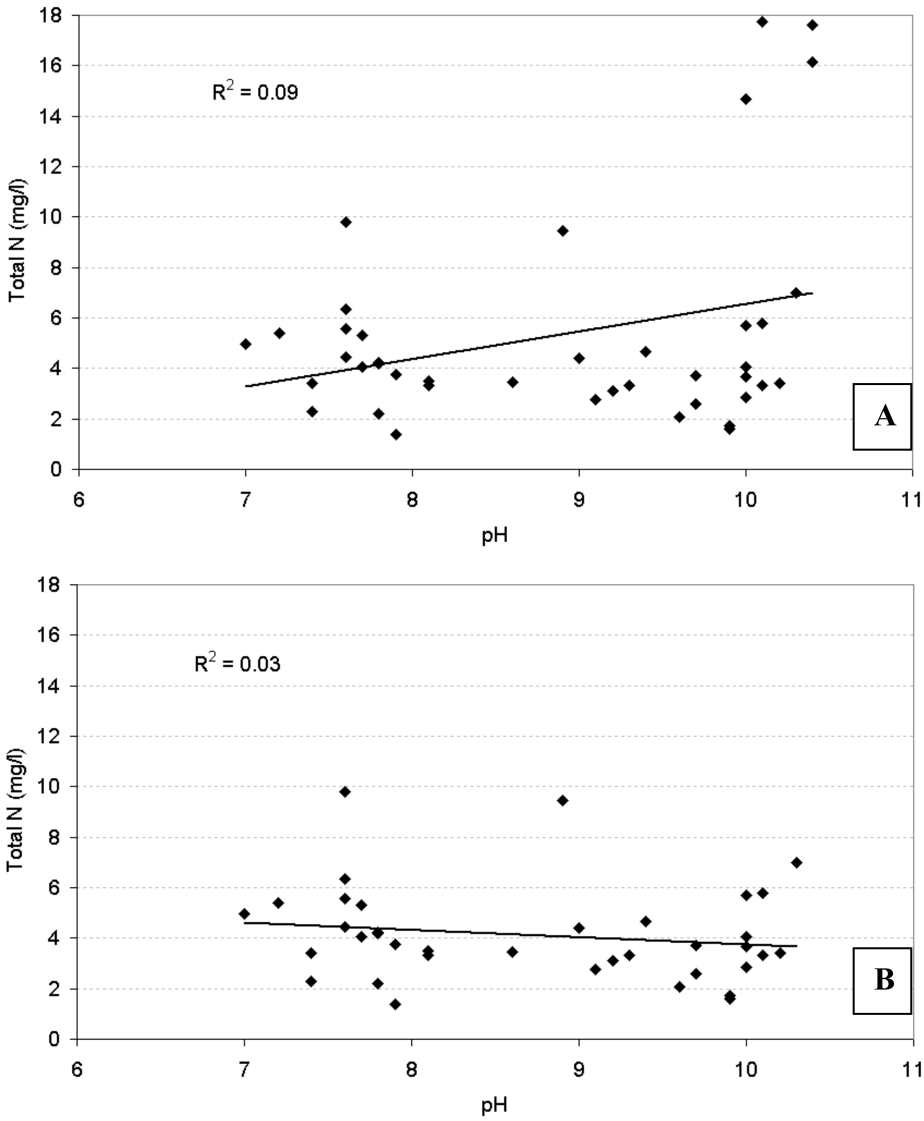


Figure 5.11 Plots illustrating (A) the apparent weak correlation between Total N and pH with outliers included; (B) the impact of removing the outliers on the apparent relationship

5.3.1.2 Chloride Results

Chloride has the potential to corrode metal pipe work (WHO, 2008) and therefore chloride values were examined to assess their potential impact. Concentrations increased during winter months and were consistently in excess of the recommended level of 2 mg/l (Figure 5.12). Evans *et al*. (2006a) compared weather data and ionic concentrations of sodium and chloride and identified that both dry and wet deposition of chloride from sea salt was a dominant source of chloride in harvested rainwater. Förster (1999) also observed that the application of de-icing salts to roads in winter resulted in airborne salt spray leading to high chloride concentrations from roof runoff. To determine if such sources and weather effects were present for this study, wind direction data from the weather dataset was processed to determine the prevailing wind directions affecting the Innovation Centre site.

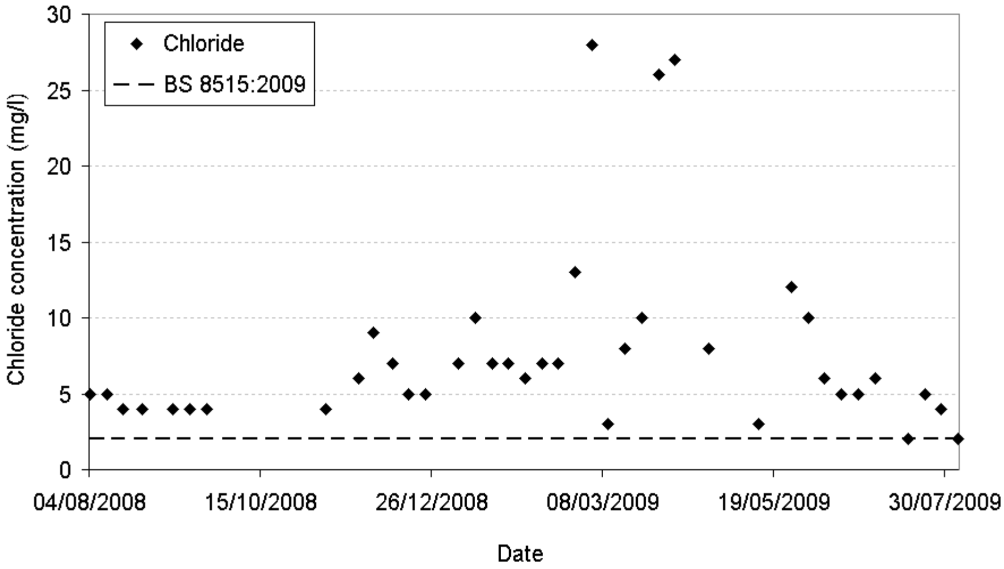


Figure 5.12 Temporal variability of chloride concentrations and comparison with the British Standard value

Average weekly (7-day) wind directions antecedent to the sampling dates were calculated (Appendix D). Examination of the data identified that average weekly prevailing winds were from the south, coastal direction (Figure 5.13). Therefore it would appear that the primary source of chloride is from sea salt. However, an additional but smaller contribution from a north-westerly direction could be the application of de-icing salts. The winter months (December to February) of 2008/09 saw below average temperatures throughout most of the UK and as mentioned in Section 5.2.3, snow occurred on one occasion. As a consequence, de-icing salt spreading on icy roads was more prevalent during this time, especially on treacherous country roads, such as those found on Dartmoor (to the north-west). Additionally, a building inspection revealed downpipes were not enclosed at the ground level. Instead, they fed into slot drains draining the car park (outlined in Section 5.2.1), which conveyed water to the RWH system main storage tank. This may have been an extra source of chloride and contributed to the elevated chloride levels. It is therefore likely that both coastal and de-icing salt sources contributed to chloride concentrations, with de-icing salt perhaps dominating in winter.

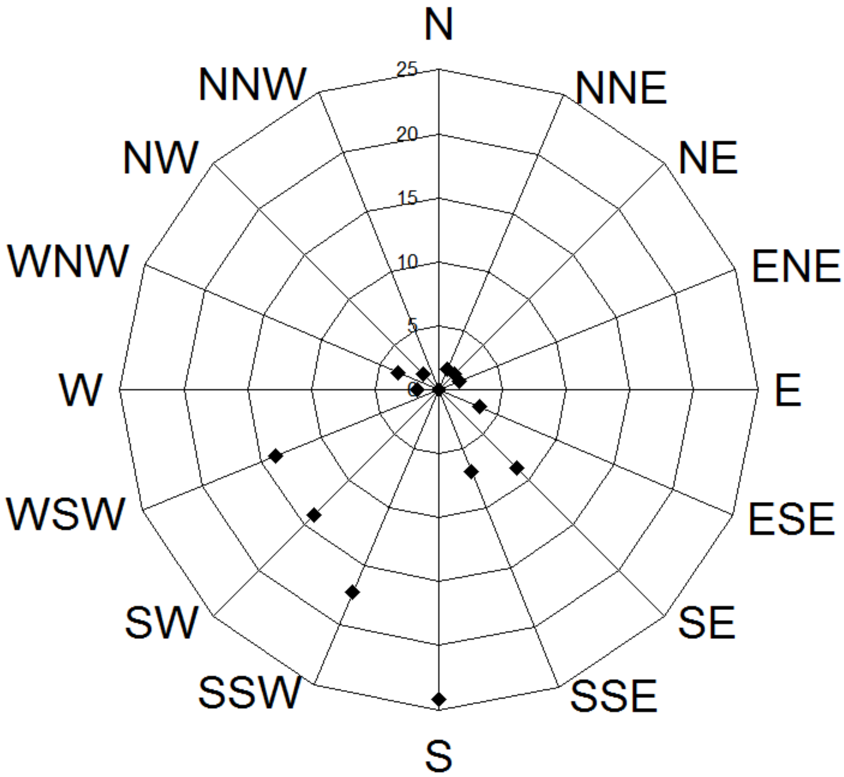


Figure 5.13 Average weekly (7-day) prevailing wind directions for the Innovation Centre (% of total number of incidences)

In order to examine this relationship further using statistical testing, a 1-tailed (directional) hypothesis was formalised, in compliance with standard practice (Kinnear and Gray, 2008):

The null hypothesis, H0, was determined to be: there is no significant correlation between wind direction and chloride concentration;

The alternate, H1, hypothesis was determined to be: there is a significant correlation between wind direction and chloride concentrations, with a southerly wind direction leading to higher chloride concentrations.

In order to test the hypothesis, the average antecedent weekly wind direction data was reclassified into two categories based on the cardinal points – south (E, ESE, SE, SSE, S, SSW, SW, WSW) and north (W, WNW, NW, NNW, N, NNE, NE, ENE) for dates corresponding to the chloride results. As the wind direction data set was categorical (i.e. not an integer), the coefficient of determination could not be utilised to examine the relationship between the two parameters. Therefore appropriate inferential statistical tests were required and the two data sets were imported into SPSS[2] for further examination. The data were initially examined using box and whisker plots within SPSS to examine the distribution of the data and determine which statistical test would be most appropriate. As can be seen from Figure 5.14, which illustrates the range of chloride concentrations for each wind direction, SPSS identified a number of extreme values (highlighted as a '*'), which have the potential to affect the results of statistical tests. The extreme values were removed and the data set re-examined (Figure 5.15), where it was identified to be suitable for further statistical analysis.

In order to select the appropriate statistical test to utilise, the data sets also needed to be examined for their distribution type (whether normal or otherwise). As the sample size for the data sets was less than 2000, the Shapiro-Wilk Test (W) of normality was utilised (a different test is appropriate where sample sizes are >2000). Consequently, it was identified that the wind direction data set was not normally distributed ($W = 0.924$, $p = 0.035$ at the $p = 0.05$ level (selected as per standard practice)). As the data was not normally distributed, the non-parametric Spearman's Rho (r_s) test was conducted (where data is normally distributed, parametric tests are used). A significant correlation was confirmed at the selected significance level (p) and the alternate hypothesis was accepted ($r_s = 0.292$, $p = 0.047$ at the $p = 0.05$ level). Therefore, there was a significant correlation between a southerly wind direction and a high chloride concentration.

The significant correlation identified between chloride concentrations and wind direction, suggests that the coastal contribution dominates the chloride contribution. Additionally, it was identified that chloride levels are consistently high. As previously mentioned, high chloride levels can have implications for the corrosion of metal pipe work and this is examined further in the following section. With regard to the extreme peaks (outliers) in chloride, these may be attributable to low rainwater levels in the tank and maintenance activities causing re-suspension of sediments on the tank bottom, with more chloride being disturbed and dissolved into the water column. However, examination of the tank sediments would be required to investigate this further, which was beyond the resources of the current study.

[2] Statistical Package for the Social Sciences, previously described in Chapter 3

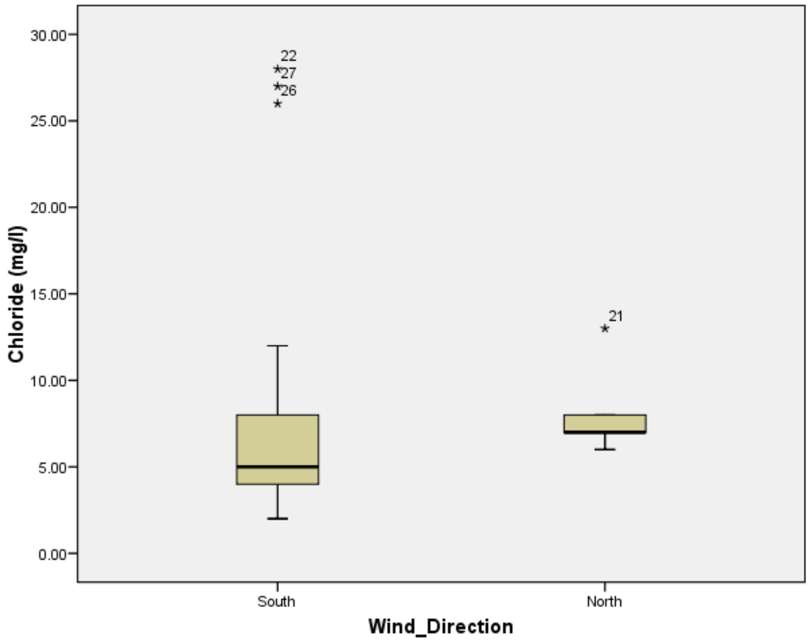


Figure 5.14 Plot illustrating the range of chloride concentrations for each wind direction, including extreme values

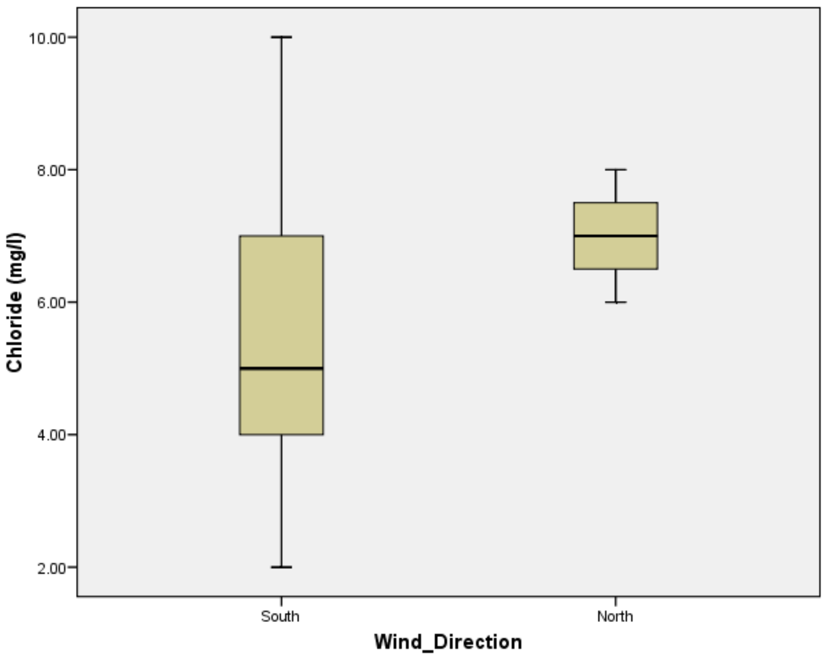


Figure 5.15 Plot illustrating the range of chloride concentrations for each wind direction, without extreme values

5.3.1.3 Metal Results

There are currently no guidelines in relation to metal concentrations in harvested rainwater; guideline values (where they exist) for *drinking* water are given in Table 5.2, merely to place the results in context. Statistical analyses were not applied to the metal results, due to the low sample number (4 samples) and therefore only descriptive summaries of the results are provided here. In the previous section it was highlighted that high chloride concentrations were present within the harvested rainwater, with potential implications for metal corrosion. Additionally, the WHO advises that pH dominates the solubility and reaction rate of most metals involved in corrosion reactions, with a low pH being implicated in corrosion. However, as the pH was consistently at a value of 7 or above, its impact is likely to be minimal. Consequently, metal concentrations are discussed primarily with regard to chloride concentrations.

Concentrations of cadmium, chromium, manganese, magnesium and nickel were generally below laboratory detection limits. For potassium, silicate and sodium there are no recognised guidelines, even by the WHO, but the concentrations observed were very low. However, potassium and silicate concentrations did decrease over time, as illustrated in Figure 5.16. Chaudhuri *et al.* (2007) observe that plants acquire significant amounts of potassium, primarily by weathering silicate materials (for example rocks such as granite). Therefore plant material can be considered an intermediate storage stage for potassium. Chaudhuri *et al.* (2007) identified that a large proportion of silicate-derived potassium in surface and ground waters is attributable to leaching of decaying plant material.

It is therefore likely that the source of silicate and potassium within the harvested rainwater is plant-derived organic matter, the most probable source of which would be the decay of leaf debris on the roof catchment. As there is a three-tiered filtration system on the RWH system, much of this organic matter is removed, which provides a possible explanation for the low potassium and silicate concentrations. Silicates in high concentrations have been described as corrosion inhibitors (WHO, 2008) and therefore the low levels present in this study may have implications for the corrosion of other metals, if other conditions are favourable (such as low calcium and low pH levels).

Calcium concentrations were very low (10 mg/l or less), (Figure 5.16), indicating very soft water and therefore should not cause scaling problems. Conversely, such low concentrations have implications for system operation – concentrations of less than 60 mg/litre can be corrosive to copper pipework in combination with an acidic pH (usually below 6.5), (WHO, 2008). As has previously been identified, pH values were usually in excess of this, which is usually sufficient to prevent corrosion. However, it was identified in Section 5.3.1.2 that chloride can also cause corrosion and Figure 5.16 illustrates there may be a relationship between chloride, sodium and potassium, as increasing values of the latter two parameters correspond to an increase in chloride. However, a larger sample and the use of statistical testing would be needed to confirm this relationship.

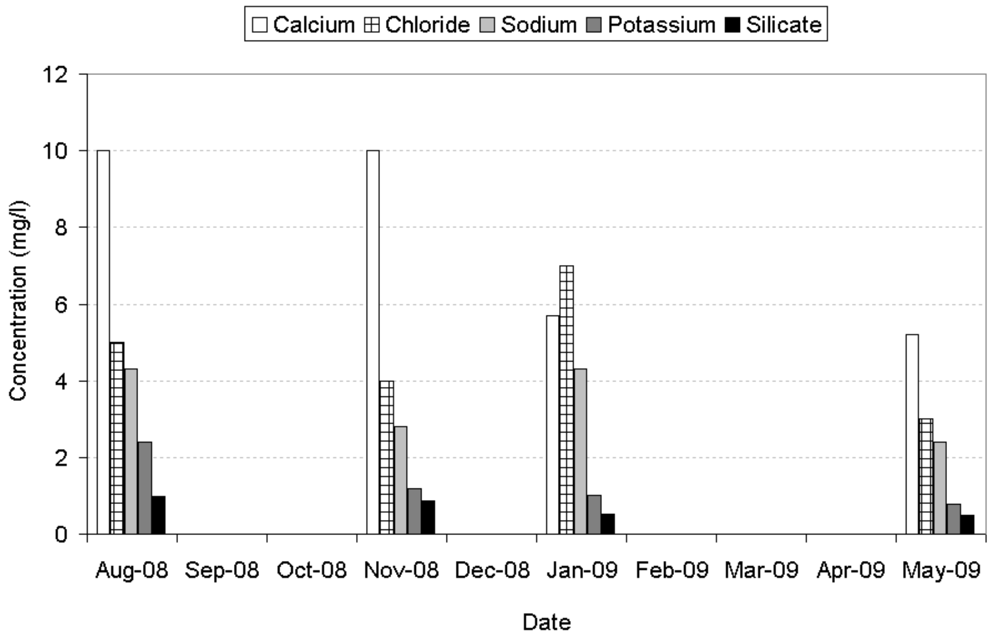


Figure 5.16 Temporal variability of calcium, chloride, sodium, potassium and silicate concentrations

Although the low sample number prevented statistical analysis, it was decided to examine the potential impact of the elevated chloride levels in relation to other metals. However, due to the range of the measured values of copper, iron, zinc, lead and aluminium, they could not easily be plotted on the same diagram. In addition, these metals were measured in µg/l and chloride was measured in mg/l. Therefore to allow all results to be plotted on the same figure and the impact of chloride to be examined, the datasets were transformed using the standard natural log (Kinnear and Gray, 2008). This transformation was also applied to the corresponding WHO guideline values, where appropriate, to place the results in context. The results of this transformation are illustrated in Figure 5.17. It appears that the impact of chloride is less straight forward than for the previously examined (potassium and sodium) metals, as levels of copper, zinc, aluminium, lead and iron did not appear to display any particular relationship to chloride concentrations.

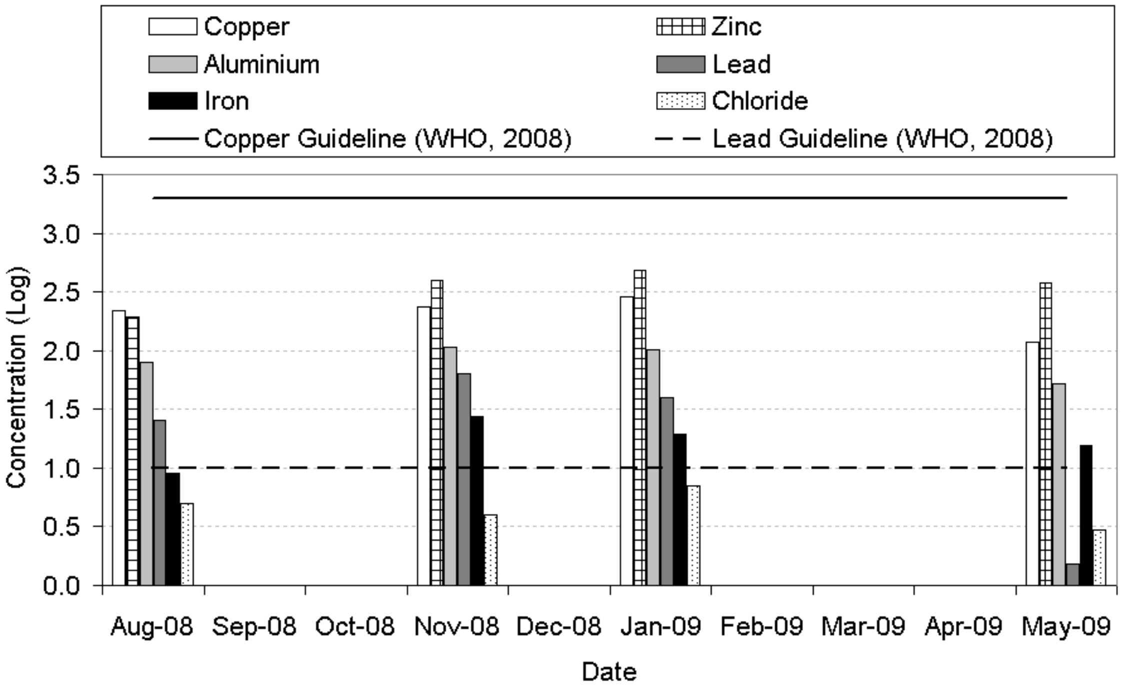


Figure 5.17 Temporal variability of metal concentrations in comparison with chloride concentrations and the WHO (2008) guideline levels (where given)

In terms of wider potential implications, it was identified that although copper concentrations were high (Figure 5.17), they were below levels observed to cause staining of sanitary-ware and the drinking water guideline level (1mg/l and 2000µg/l, respectively; WHO, 2008). The presence of copper is known to increase the corrosion of galvanized iron and steel fittings, but such an interaction was not observed as iron concentrations were below levels known to promote the staining of plumbing fixtures (300 µg/l; WHO, 2008).

Relatively high zinc levels were observed, a source of which could be vehicle parts. Luker and Montague (1994) identified zinc in highway runoff originated from the action of rainwater on tyres and brakes. Additionally, upon undertaking a building inspection of the Innovation Centre, it was identified that the downpipes were not enclosed at the ground level. Instead, they fed into slot drains which drained the car park (outlined in Section 5.2.1), which then conveyed water via the surface water drainage system to the RWH system main storage tank. Therefore the high levels of zinc could have arisen from car park runoff inadvertently entering the RWH main storage tank due to inappropriate drainage design. An alternative, or additional, source of zinc could be from soft water corrosion of brass fittings, which is possible as the harvested rainwater was found to be very soft.

Lead levels were in excess of drinking water guidelines (10µg/l) most likely due to the softness of the water, but due to the high pH of the harvested rainwater, levels were below those expected if lead fittings plumbosolvency was occurring (100 µg/l; WHO, 2008).

Aluminium concentrations were between 52.3 and 108 µg/l. The latter value is on the boundary for the deposition of aluminium hydroxide floc (100-200 µg/l; WHO, 2008), posing a potential source of contamination to storage tank sediments. The main source of aluminium is likely to be the aluminium downpipes. These are coated with a protective powder on the exterior but not on the interior; therefore runoff comes into direct contact with and potentially dissolves the uncoated aluminium. An additional source may be the previously mentioned car park to RWH tank drainage. Had the likelihood of the presence of soft water been assessed during the building design phase, a different material may have been selected or the coating also applied to the interior, as well as the car park drainage being designed more appropriately.

It would appear the previously mentioned low potassium levels do not exude a significant interaction with metal dissolution, as concentrations of most metals decreased over time. Most metal concentrations peaked in autumn, but a larger data set would be required to clarify seasonal effects. Overall, it was concluded the main impact on metal concentrations was the soft nature of the rainwater harvested at the Innovation Centre site. Consequently, non-metallic fittings and pipe work would have perhaps been more appropriate. What could not be ascertained from the study is whether the rainwater falling at the site is soft, or whether the softness results from site-based influences. Further study would be needed to clarify this, in order to recommend if rainwater samples should be taken when RWH is considered at a site, to allow such parameters to be taken into consideration when designing both internal and external system fittings.

5.3.1.4 Other Physicochemical Parameter Results

Oil and grease and PAH showed concentrations below the laboratory detection limits. This would indicate that airborne particulate deposition from possible nearby sources (car parks, railway) is negligible. This also indicates that the bitumastic-felt-membrane roof covering is, at present, not being significantly leached during runoff processes. These levels are in contrast to the findings of Förster (1999) and represent a low risk to both health and RWH system (filter) operation. However, as the building is less than two years old, the contribution made by the roof covering may change over time and further monitoring would be required to quantify this.

Phosphorous levels never exceeded 50 μg/l and sulphate 5.3 mg/l, therefore are unlikely to present risks for either health or system function. Conductivity ranged from 44 to 261 μS/cm. Turbidity levels averaged 1.7 with a range from 0.3 to 9.7, thus never exceeding the BS 8515:2009 recommended level of 10 NTU. This corroborated visual inspections, which observed that the harvested rainwater was '*visually clear and free from floating debris*' and therefore compliant with the UK standard (BSI, 2009). Total dissolved solids (TDS) ranged from 30 to 183 mg/l, which is well below the recommended acceptable *aesthetic* criteria for *drinking* water (600 mg/l; WHO, 2008). Biochemical oxygen demand (BOD) remained below 3 mg/l throughout the study and chemical oxygen demand (COD) below 12 mg/l, which are similar to values found in treated water (Wheatley and Surendran, 2008). These results indicate that the health hazard from general chemical parameters is low, should harvested rainwater from the system be accidentally ingested.

With regard to pH, values always exceeded the recommended lower pH level of 5 and exceeded the higher recommended level of 9 in 51% of samples (Figure 5.18). As discussed in Section 5.3.1.3, this meant that there was no corrosion of metals attributed to low (acidic) pH values.

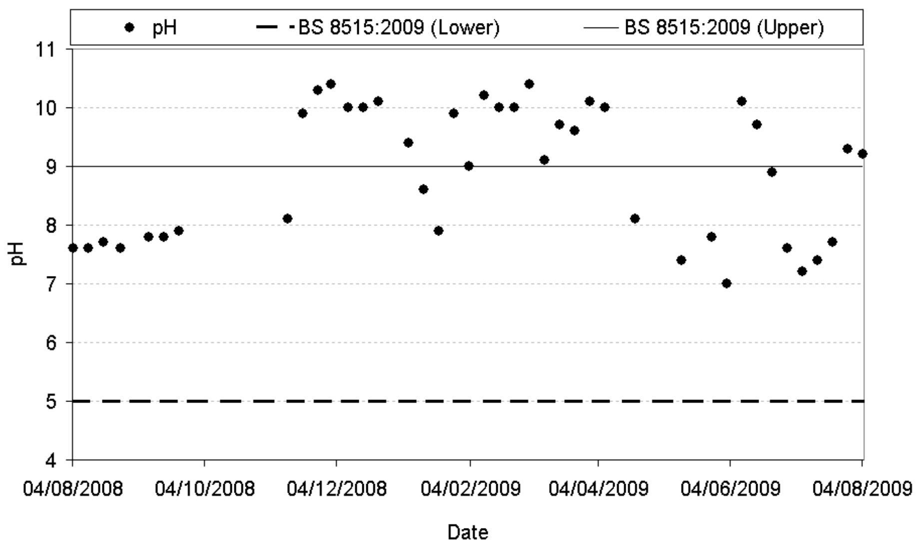


Figure 5.18 Temporal variability of pH values and comparison with the British Standard values

5.3.2 Microbiological Parameter Results

The risk to health from microbiological contaminants is assessed using faecal indicator organisms (FIOs), other bacteria and some protozoa. These have the potential to cause infection and illness or indicate the presence of other organisms with this potential (WHO, 2008). No incidence of the bacteria *Salmonella* was recorded during the study and only one incidence of the protozoa *Cryptosporidium* was recorded, at a level of 0.1 oocyst/L. An independent environmental services company conducted a spot check for the bacteria *Legionella* and no presence was detected. In terms of FIO organisms, however, results were very different with their presence recorded in a large proportion of samples. However, faecal coliform (FC) counts never exceeded the recommended guideline (EC Bathing Water Directive, 1975, from MTP (Brown, 2007)) and total coliform (TC) counts exceeded the recommended guideline only once.

In contrast, counts for the FIO *Enterococcus faecalis*, (previously known as *Streptococcus faecalis*; faecal strep), regularly exceeded the guideline level of 100/100ml, with counts as high as 1460/100ml and the average being 184/100ml (Figure 5.19). The temporal variation in counts for the three FIOs (TC, FC and *E. faecalis*) are summarised in Figure 5.19, along with guideline values (outlined in Table 5.1) as comparators. In order to plot these data series together a log transformation was performed, in the manner previously outlined in Section 5.3.1.3.

Flahaut *et al.* (1997) identified that the pH response of *E. faecalis* seemed to be different to gram-negative bacteria, such as faecal coliforms. Furthermore, Hartke *et al*. (1998) observed that *E. faecalis* was able to survive for prolonged periods in oligotrophic (nutrient poor) conditions. This provides an explanation as to why the low nitrogen levels (described in Section 5.3.1.1) may not have had an impact on the growth of *E. faecalis*. Alternatively, the low levels may result from *E. faecalis* utilising these metabolites during growth. Additionally, the WHO (2008) summarise that *E. faecalis* tends to survive longer in water environments than FC and are relatively tolerant of sodium chloride and alkaline pH levels. It was therefore decided to examine the relationship between FC, TC, *E. faecalis* and pH. A null and alternate hypothesis were formalised as follows:

H0 – there is not a significant difference between FIO counts and pH value;

H1 – there is a significant difference between FIO counts and pH value.

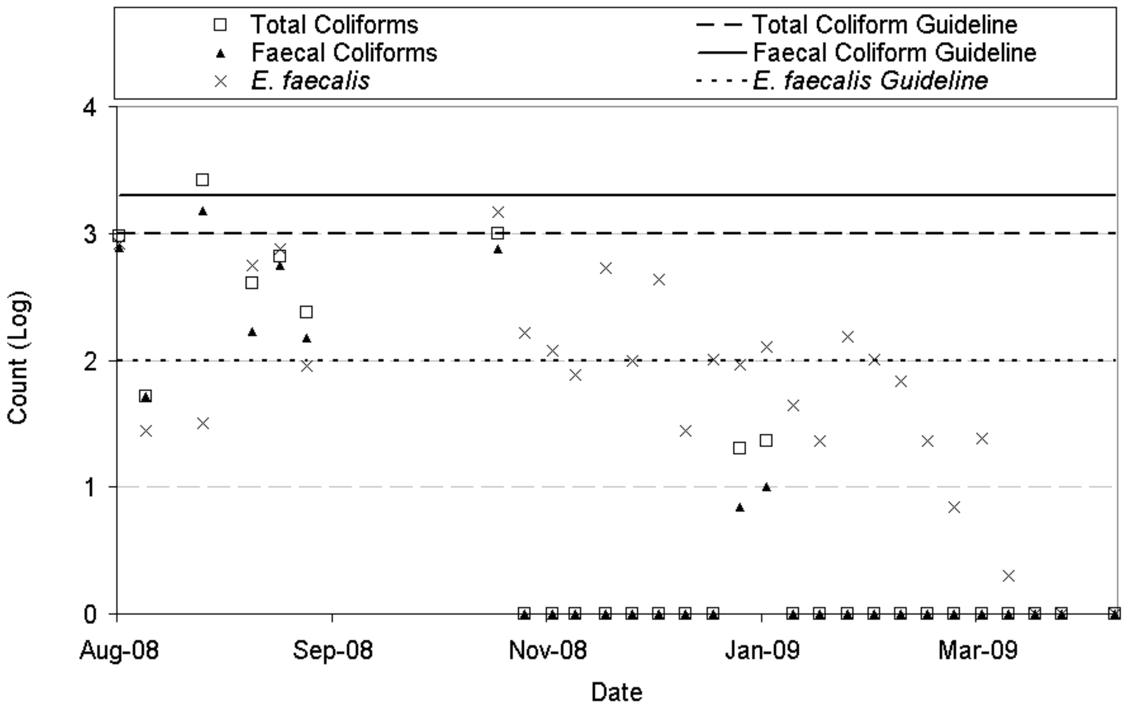


Figure 5.19 Total coliform, Faecal coliform and *E. faecalis* counts (log) in comparison with guideline values

As multiple parameters were being examined, the use of a coefficient of determination or other simple statistic was not appropriate and therefore the data series were imported into and explored within SPSS, in the manner previously described in Section 5.3.1.1. Exploration within SPSS led to the application of a 2-tailed Pearson's Product Moment test for correlation. This revealed a significant correlation between each of the microbiological parameters, as well as between pH and both TC and FC counts at the $p = 0.05$ and $p = 0.01$ significance levels. The results of the statistical analysis is summarised in Table 5.3, where a single asterisk indicates a significant result at the $p = 0.05$ level and two asterisks indicate a significant result at the $p = 0.01$ level and 'N' is the sample number. However, there was not a significant correlation between pH and *E. faecalis* counts at either the $p = 0.05$ or 0.01 significance levels. This is inline with the previous discussion on pH having a less significant impact on *E. faecalis*. It is therefore likely that the pH levels measured, along with the high chloride levels, are responsible for low FC counts, but are less detrimental to *E. faecalis*.

Table 5.3 Results of the Pearson's Product Moment statistical analysis between microbiological parameters and pH

		Total_ Coliform	Faecal_ Coliform	E_Faecalis	pH
Total_Coliform	Pearson Correlation	1	.961**	.349*	-.421**
	Sig. (2-tailed)		.000	.025	.007
	N	41	40	41	40
Faecal_Coliform	Pearson Correlation	.961**	1	.453**	-.374*
	Sig. (2-tailed)	.000		.003	.019
	N	40	40	40	39
E_Faecalis	Pearson Correlation	.349*	.453**	1	-.176
	Sig. (2-tailed)	.025	.003		.277
	N	41	40	41	40
pH	Pearson Correlation	-.421**	-.374*	-.176	1
	Sig. (2-tailed)	.007	.019	.277	
	N	40	39	40	40

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

With regard to sources of FIOs, Evans *et al.* (2006a) highlight the contribution of airborne micro-organisms to harvested rainwater quality. As previously identified, one of the dominant wind directions was from the south. Airborne bacteria from a WWTP located to the south could be a potential source, although further research would be required to quantify this effect. Additionally, faecal enterococci are entirely related to the intestinal tract of humans and other animals (WHO, 2008). As such, a more probable source of *E. faecalis* was identified as being bird faeces deposited on the roof catchment area (Figure 5.20, Item Ai). On conducting a building inspection, it was discovered that runoff passes over two roof surfaces. Initially it lands on a raised, sloped area that is open underneath (Figure 5.20, Item A), from where it is diverted via a downpipe to a second, flatter roof area, which has a covering of algae (Figure 5.20, Item B). The algal growth is exacerbated by the use of bitumastic-felt, as it is difficult to clean thoroughly. A flock of birds had set up roost in the open area resulting in the runoff flowing through and stagnating by substantial covering of avian faeces (Figure 5.20, Item Ai). It was also observed that the flat area was being used for the storage of items, such as wooden crates and PVC pipes.

Additionally, some debris screens were covered with organic matter, including leaves, feathers and relocated faeces (Figure 5.20, Item C). Furthermore, downpipe hoppers were not covered (Figure 5.20, Item D), allowing debris to collect and birds to perch. Some downpipes feeding into drains connected to the RWH system were also identified as being open to ground-level (path) catchment areas (Figure 5.20, Item E). Ground level catchments were not accounted for in the design of the RWH system and therefore no devices are included to manage pollution from such sources. All the features identified had the potential to compromise the quality of the harvested rainwater and offer an additional explanation for the high *E. faecalis* counts.

Furthermore, as described in Chapter 6, Section 6.3.1, the float switches on the RWH system header tanks were incorrectly configured during the period from November 2007 to September 2008. This meant that more mains water top-up was being used than harvested rainwater. This led to the potential for the residence time to be increased and therefore exerting a possible additional impact on the harvested water quality. However, this phenomenon was not investigated in detail during this study (as overflow incidents could not be monitored and these would need incorporating) and further work would be required to quantify its impact.

Unfortunately the building was designed and constructed before the British Standard on the installation of RWH systems was released (BSI, 2009). This recommends that roof outlets, guttering and pipework should be considered as a fundamental part of the RWH system. Additionally, it recommends that sealed gullies are used at ground level to reduce the risk of contaminants entering the system. The detrimental building design features identified in this study highlight the importance of raising awareness about and implementing the British Standard. Furthermore, the standard does not mention the use of first flush devices, which can contribute to increasing harvested rainwater quality (CRC, 2005; Fewtrell and Kay, 2007; Martin *et al.*, 2007; WHO, 2008).

5.3.3 Remedial Action

Upon identification of the above issues, actions were recommended to limit impacts to harvested rainwater quality by extending the building maintenance schedule to include periodic cleaning of the roof, debris screens and hoppers. Additionally, options to limit microbial counts were considered, which included installation of netting to the open roof area to prevent the entry of birds or the installation of a UV disinfection device. The extra cost of implementing and maintaining such measures could have been avoided if the building's roof design had been considered with respect to the RWH system and harvested rainwater quality.

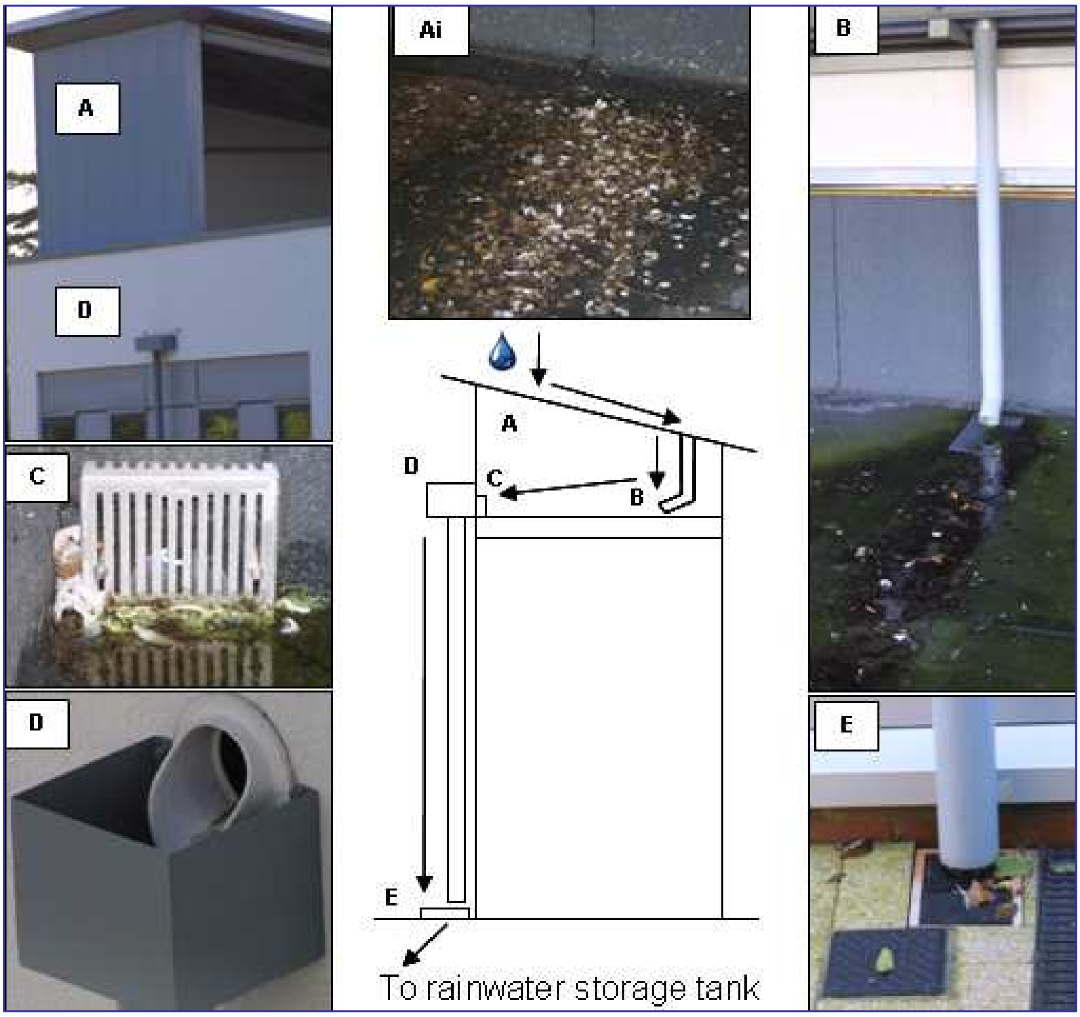


Figure 5.20 Inappropriate design features of the Innovation Centre with the potential to compromise harvested water quality (refer to text for a description of each item)

5.4 The Impact of Antecedent Weather Conditions

Previous studies (Evans *et al.*, 2006b; Fewtrell *et al.*, 2009) have established that the length of the dry and/or wet period (the antecedent condition) between sampling events can influence harvested rainwater quality – in particular microbiological parameters. This is primarily due to the deposition of matter or bacteria during dry periods and the subsequent flushing effect caused when a rainfall event occurs, causing runoff to disturb the deposited matter. The previous section highlighted that *E. faecalis* levels were consistently high and were not significantly affected by changes in pH level. It was therefore decided to examine the impact of antecedent weather conditions on this FIO, as well as other parameters known to be affected by antecedent conditions, such as

TDS, chloride and nitrogen levels. In line with the previously outlined standard procedure for the selection of a statistical test (Section 5.3.1.1), the following (1-tailed) hypothesis was formalised:

H0 – there is not a significant difference between parameter values for dry and wet periods;

H1 – there is a significant difference between parameter values for dry and wet periods, with wet periods producing higher values for each parameter.

5.4.1 Antecedent Weather Condition Data Analysis

Fewtrell *et al.* (2009) examined the impact of 24 hour antecedent conditions on harvested rainwater microbial quality. This study examined the effect of antecedent conditions on FIO and identified the occurrence of FIO increased in RWH tanks 24 hours after rainfall events in excess of 5mm (Fewtrell *et al.*, 2009). Therefore it was decided to investigate the impact of antecedent dry and wet periods on the following parameters:

- TC
- FC
- *E. faecalis*
- pH
- TDS
- Chloride
- Nitrogen

These parameters were chosen as they have been highlighted in the previously mentioned research, their values were highly variable within the present study and they were perhaps the most likely to be affected by antecedent weather conditions. In line with the previous study by Fewtrell *et al.* (*2*009) rainfall data from the previously outlined Whipton weather station (Section 5.2.3) was divided into two groups – dry and wet. A 5mm rainfall volume cut off was established inline with Fewtrell *et al.* (2009). The 5mm cut off was utilised to distinguish between dry and wet periods; anything less than 5mm was considered to be a dry period and anything above 5mm a wet period. In addition, it was decided to examine the impact of the length of dry and wet antecedent conditions and therefore the rainfall data was further processed to yield dry and wet events for the following antecedent durations:

- 24 hours
- 48 hours
- 72 hours
- 7 days

The rainfall data was aggregated for each antecedent duration prior to a sampling event. For example, for the 1 week antecedent duration the rainfall on the 7 days preceding the sampling day was totalled. It should be noted that as the samples were taken mid-morning, the rainfall total on the actual sampling date is included for the antecedent durations, in case a high intensity event occurred on the morning the sample was taken. The number of dry and wet events for different antecedent periods derived from the data are summarised in Table 5.4.

Table 5.4 The number of dry (<5mm rainfall) and wet (>5mm rainfall) events during the monitoring duration for different antecedent durations

Antecedent duration	Number of Dry Events	Number of Wet Events	Antecedent duration	Number of Dry Events	Number of Wet Events
24 hour	30	11	72 hour	21	20
48 hour	25	16	7 days	18	23

When the processing of the data had been completed, statistical analyses were performed to identify relationships between the antecedent conditions and the aforementioned parameters.

5.4.1.1 Antecedent Weather Condition Statistical Analysis

A set of data and output files was created in SPSS for the three microbiological parameters, as each dataset had the same number of data points in each group. A second set of files was created for the three physicochemical parameters of pH, nitrogen and TDS. Finally, a third set of files was created for chloride, as due to some data points being below the laboratory detection limits the data set had a different number of data points to the other parameters. A data and output file was created for each set of parameters for each of the antecedent durations, as the number of dry and wet periods in each varied.

Each data set was first examined using SPSS, including use of the Kolmogorov-Smirnov (K-S) test (suitable for sample sizes <2000). These examinations revealed that some of the data sets were not normally distributed. For example, Figure 5.21 illustrates that the *E. facalis* data for the 24 hour dry antecedent period was heavily positively skewed (a long tail to the right). Further investigation, in the form of box and whisker plots, revealed a number of outliers (‘o’) and extreme cases (‘*’) (Figure 5.22), (box and whisker plots for other parameters are located in Appendix E). The outlying data points had the potential to distort the results of the statistical analysis (Kinnear and Gray, 2008). As previously demonstrated, where only a small number of outlying or extreme cases are present, it is acceptable to remove the values.

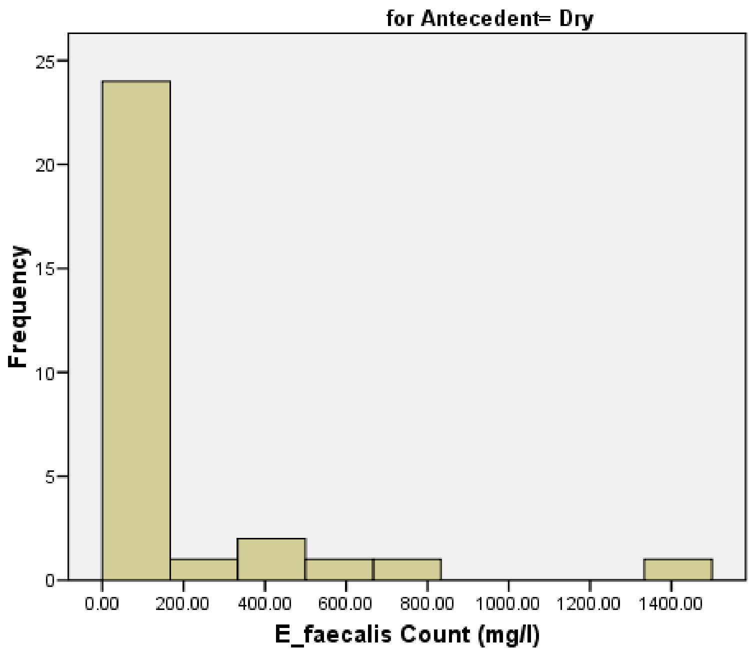


Figure 5.21 The heavy positive skew of the *E. faecalis* 24 hour dataset

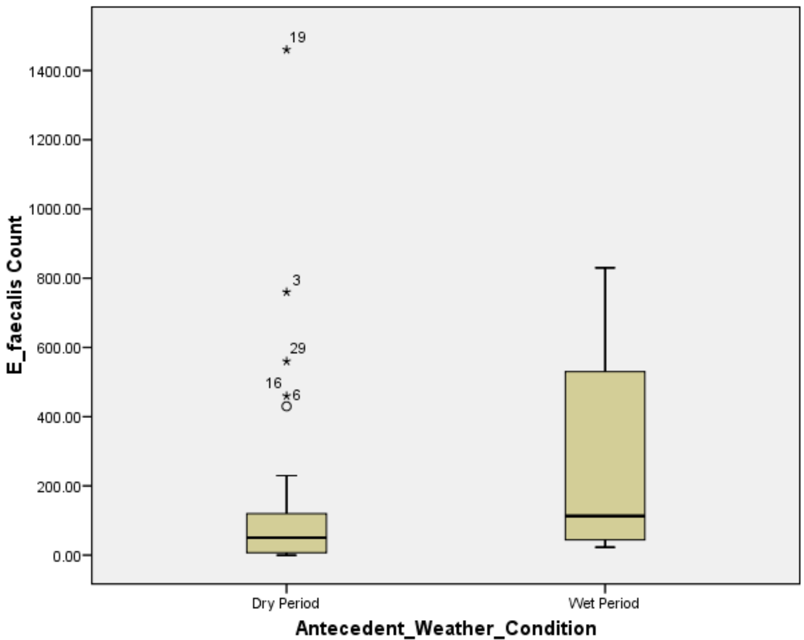


Figure 5.22 The range of *E. faecalis* counts for dry and wet periods for the 24 hour antecedent duration, including outliers and extreme values

However, when a large number of these values are present (such as in the *E. faecalis* dataset), it is more appropriate to apply a data transformation. In the case of *E. faecalis* and inline with the previous study by Fewtrell *et al.* (2009), a $\log_{10}$ transformation was utilised to normalise the data. A $\log_{10}$ transformation within SPSS can only be applied to data values greater than 0, therefore 1 was added to any data points with a value of zero. For the *E. faecalis* dataset, the transformation resulted in a $\log_{10}$ dataset with an approximately normal distribution (Figure 5.23) and no outliers or extreme cases (Figure 5.24). This permitted the use of the parametric Student's T-test. Where datasets did not display normal distributions, even after applying a transformation (such as squaring for negative skewness), the non-parametric Mann-Whitney test was applied, but to the untransformed data. As recommended by Kinnear and Gray (2008), the exact, rather than asymptotic, p-values are reported for the Mann-Whitney test results. Table 5.5 summarises the transformation and test applied for each parameter considered.

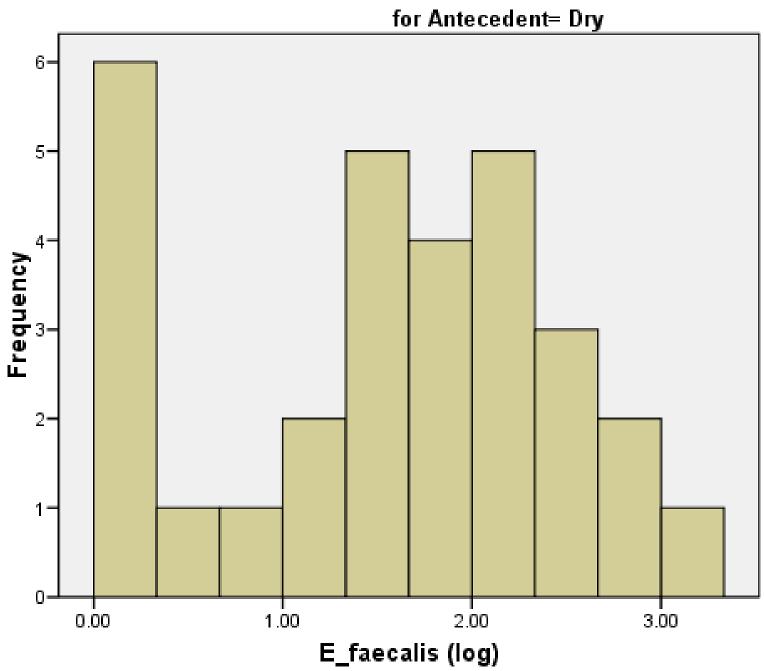


Figure 5.23 The normalised ($\log_{10}$ transformed) *E. faecalis* 24 hour dataset

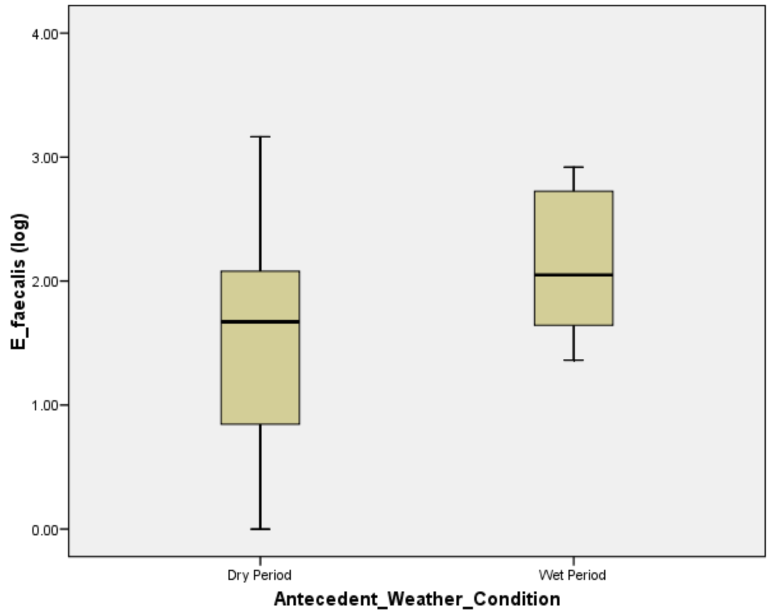


Figure 5.24 The $\log_{10}$ transformed range of *E. faecalis counts* for dry and wet periods for the 24 hour antecedent duration

Additionally, as dry and wet group sizes were not equal (for all antecedent periods, although those for the 72 hour duration were almost equal at 21 and 20, respectively), the independent samples t-test was utilised. Furthermore, the Levene statistic (*F*) was used to determine the homogeneity of variance between the groups. Where the Levene statistic indicated unequal variances ($p = <0.05$) an unequal variances (separate) test result was used and where variances were indicated to be equal ($p = >0.05$) an equal variances (pooled) test result was used. In each case the significance of the result was evaluated at the $p = 0.05$ level, by comparing this value with the significance value for the test result. Where the significance value for the test was $<=0.05$, a significant result was indicated. The results of the statistical tests are summarised and discussed in the following section.

Table 5.5 Summary of data transformations and statistical tests applied to each parameter in relation to antecedent weather condition

	Parameter	Normally distributed?	Skew	Transformation	Statistical Test
24-hour	*E. faecalis*	No	+ve	Log_{10}	Student's T-test
	TC	No	+ve	Log_{10}	Mann-Whitney
	FC	No	+ve	Log_{10}	Mann-Whitney
	Cl	No	+ve	Log	Mann-Whitney
	pH	No	-ve	Square root	Mann-Whitney
	TotalN	No	+ve	Log_{10}	Mann-Whitney
	TDS	No	+ve	Log_{10}	Mann-Whitney
48-hour	*E. faecalis*	No	+ve	Log_{10}	Student's T-test
	TC	No	+ve	Log_{10}	Mann-Whitney
	FC	No	+ve	Log_{10}	Mann-Whitney
	Cl	No	+ve	Log	Mann-Whitney
	pH	No	-ve	Square root	Mann-Whitney
	TotalN	No	+ve	Log_{10}	Student's T-test
	TDS	No	+ve	Log_{10}	Mann-Whitney
72-hour	*E. faecalis*	No	+ve	Log_{10}	Student's T-test
	TC	No	+ve	Log_{10}	Student's T-test
	FC	No	+ve	Log_{10}	Student's T-test
	Cl	No	+ve	Log	Mann-Whitney
	pH	No	-ve	Square root	Mann-Whitney
	TotalN	No	+ve	Log_{10}	Mann-Whitney
	TDS	No	+ve	Log_{10}	Mann-Whitney
7-day	*E. faecalis*	No	+ve	Log_{10}	Mann-Whitney
	TC	No	+ve	Log_{10}	Mann-Whitney
	FC	No	+ve	Log_{10}	Mann-Whitney
	Cl	No	+ve	Log_{10}	Mann-Whitney
	pH	No	-ve	Square root	Mann-Whitney
	TotalN	No	+ve	Log_{10}	Mann-Whitney
	TDS	No	+ve	Log_{10}	Mann-Whitney

5.4.2 Antecedent Weather Condition Analysis Results

Table 5.6 illustrates the results of the statistical analysis undertaken in the previous section.

Table 5.6 Statistical test results for each parameter and antecedent duration

Antecedent duration	Parameter	*F**	*p**	*t* or *u**	*p** (1-tailed)	H0* accept/reject
24-hour	*E. faecalis*	3.139	0.084	-1.778	**0.042**	**Rejected**
	TC	NA	NA	129.000	0.264	Accepted
	FC	NA	NA	130.500	0.274	Accepted
	Cl	NA	NA	127.000	0.290	Accepted
	pH	NA	NA	140.500	0.239	Accepted
	TotalN	NA	NA	139.000	0.230	Accepted
	TDS	NA	NA	98.000	**0.045**	**Rejected**
48-hour	*E. faecalis*	4.763	0.035	-1.811	**0.039**	**Rejected**
	TC	NA	NA	152.500	0.166	Accepted
	FC	NA	NA	157.000	0.203	Accepted
	Cl	NA	NA	120.500	**0.043**	**Rejected**
	pH	NA	NA	173.500	0.242	Accepted
	TotalN	0.159	0.692	0.416	0.340	Accepted
	TDS	NA	NA	109.000	**0.007**	**Rejected**
72-hour	*E. faecalis*	1.159	0.289	-2.088	**0.022**	**Rejected**
	TC	1.020	0.325	-.700	0.246	Accepted
	FC	0.342	0.568	-1.630	0.063	Accepted
	Cl	NA	NA	132.000	0.054	Accepted
	pH	NA	NA	204.000	0.441	Accepted
	TotalN	NA	NA	197.500	0.376	Accepted
	TDS	NA	NA	134.000	**0.024**	**Rejected**
7-day	*E. faecalis*	NA	NA	112.500	**0.010**	**Rejected**
	TC	NA	NA	158.500	0.143	Accepted
	FC	NA	NA	173.500	0.255	Accepted
	Cl	NA	NA	119.500	**0.025**	**Rejected**
	pH	NA	NA	203.500	0.466	Accepted
	TotalN	NA	NA	164.500	0.135	Accepted
	TDS	NA	NA	101.000	**0.002**	**Rejected**

*F = the Levene Test statistic; p = significance level; t = the Student's T-test statistic; u = the Mann-Whitney Test statistic; H0 = the null hypothesis

It was identified that there were no significant differences in parameter values during dry or wet periods for TC, FC, pH and total nitrogen, as for these parameters the null hypothesis was accepted for each of the four antecedent weather condition durations. Therefore, in contrast to previous studies, it would seem that levels of these parameters were not significantly affected by antecedent periods within this study.

However, for *E. faecalis*, TDS and chloride there were statistically significant differences, indicated by acceptance of the alternate hypothesis for each of the four antecedent weather condition durations for *E. faecalis* and TDS and for the 48-hour and 7-day durations for chloride. This indicates that a longer dry period antecedent to a rainfall event and a consequent sampling event has a significant impact on the concentrations of these parameters than shorter dry antecedent durations. Therefore it can be inferred that levels of *E. faecalis* and TDS are influenced by flushes of rainfall after antecedent dry periods between 24 hours and 7 days and chloride levels are influenced by 48 hour or 7 day dry periods. This is in line with the findings of previous studies (Section 5.4). This indicates that FIO numbers are likely to increase in harvested rainwater storage tanks after rainfall-runoff is produced from roof catchments after dry periods. This may provide an explanation for the high *E. faecalis counts* observed in this monitoring programme, highlighting the potential contribution of runoff passing through the identified sources of avian faeces. However, sampling of the faeces to confirm it as the source of *E. faecalis* would need to be undertaken.

In comparison to the previous study by Fewtrell *et al.* (2009), there is a difference between the TC and FC levels – with this study finding no significant difference between wet and dry 24 hour antecedent periods. This may be attributable to differences in the slope of the roof catchment area – in the previous study the roof was sloped, but in the present study the roof was flat, thus water may take longer to gravitate towards the collection pipe work and the main storage tank. However, a similarity between the two studies was identified, that being that *E. faecalis* was found to have greater endurance on roof surfaces than either TC or FCs. The results reinforce that *E. faecalis* is incredibly robust and consideration should have perhaps been given to fitting a first flush device to the RWH system to divert particularly contaminated volumes of runoff, to increase the harvested rainwater quality.

No first flush device was present in the system monitored in either study. The use of first flush devices is not covered within the recent British Standard (BS 8515:2009). Their inclusion was carefully considered, but it was felt they were more appropriate for systems in developing countries and there was not enough research on their application in developed countries to warrant recommendation of their inclusion (Grigson, 2010). It is suggested that further research into the use of such devices in the UK should be undertaken to potentially revise this omission as their inclusion could be less costly than

UV (as a device is a one off item, whereas UV requires cartridge replacements and energy to function). This would promote increased harvested rainwater quality, keeping in mind public perceptions of risk associated with harvested rainwater quality. Additionally, if the rainwater was being used for other non-potable purposes, such as lawn irrigation via sprinklers, the potential health implications of the Innovation Centre RWH system harvested rainwater quality may have been greater due to an increased likelihood of contact (and as the BS 8515:2009 guideline level for *E. faecalis* for such uses is 1/100ml, which was frequently exceeded).

The persistent nature and measured levels of *E. faecalis* on the catchment surface would appear to represent the greatest health-based risk (probability and severity of a health impact) from the monitored RWH system. *E. faecalis* is present in the intestinal tract of humans and birds, where a non-pathogenic (non-disease causing) commensal relationship (one organism benefits but the other is unaffected) usually exists (Fraser *et al.*, 2009). In some cases, particularly in hospital environments and in individuals with poor immune systems, *E. faecalis* has been isolated from wounds and infections and displays high levels of antibiotic resistance (Varman *et al.*, 2009). It has also been associated with endocarditis (inflammation of the inner layer of the heart). However, determining whether *E. faecalis* is the primary pathogen or only a contributor via a polymicrobial infection is often difficult (Fraser *et al.*, 2009).

Wound-related infections are perhaps one of the most relevant health effects for the present study; aerosols from WC flushing with harvested rainwater could come into contact with wounds on the individual flushing the WC. Additionally, although *E. faecalis* is primarily non-pathogenic and generally used as a FIO, not a direct indicator of infection, concentrations in excess of 32/100ml have been correlated to gastroenteritis in bathers compared to non-bathers, although no direct causal relationship was established (Kay *et al.*, 1994). In light of these potential health risks and in order to determine the health implications from flushing a WC with harvested rainwater containing *E faecalis* in an office-based setting, the next section will apply a Health Impact Assessment (HIA) approach to the results presented in this section.

5.5 Implementing a Health Impact Assessment (HIA)

BS 8515:2009 advocates the use of the WHO endorsed 'water safety plan' approach to protecting the safety of water supplies, involving the use of risk assessments and risk management. Such an approach considers potential sources of contamination to a system. However, this approach is particularly tailored for large water distribution systems and potable water, therefore its use in application to RWH could be disputed. A more recent and emerging approach endorsed by the WHO (2009) for the assessment of risk of programmes or projects is the application of a HIA. HIA has become increasingly important as a drive towards managing and mitigating health-based consequences of development has moved up the political agenda (Fewtrell and Kay, 2008).

A HIA is primarily qualitative and seeks to identify the types of hazard to which programme participants are exposed. It can be adapted to be quantitative via the use of quantitative microbial risk assessments (QMRA), (Fewtrell and Kay, 2008). To be of most benefit, HIAs should be undertaken *prior* to the implementation of a programme or system. This helps to highlight potential health impacts, which can be incorporated in project planning from the beginning. HIAs also support estimation of positive and negative, intended or unintended, direct or indirect and single, multiple or cumulative health impacts, whilst supporting the pillars of sustainable development (economic growth, environmental protection and social equity) (Fewtrell and Kay, 2008).

The HIA process is summarised in Figure 5.25, which illustrates the number of stages undertaken in a full HIA, usually prior to the implementation of a programme, consisting of risk assessment, hazard identification, exposure assessment, risk characterisation, optional QMRA (where appropriate) and the resulting health impact statement. The risk assessment stage acts as a screening exercise and quickly provides a general overview of the health relevance of a project. In relation to RWH, Fewtrell *et al.* (2008) identify the main hazards as drowning or near-drowning, injury and infection. The hazard identification stage goes into greater depth and identifies the key health issues and concerns of the project. These issues and concerns are then formalised into the exposure assessment, optional QMRA and risk characterisation stages to produce the health impact statement.

During these stages a rapid or in-depth appraisal of the hazards is undertaken using available evidence, such as data from health and safety records or ascertaining (where possible) dose-response relationships and probabilities of exposure for microbiological hazards within a QMRA. A dose-response relationship relates the amount of the infection causing hazard to the resulting health affect (usually illness). The probability of exposure relates the source of exposure to the likelihood of entering into contact with a source or the frequency with which a source may be contaminated. A severity weight and duration are also incorporated, to account for the impact and length of the health affect (Fewtrell and Kay, 2008). It is at the exposure assessment and QMRA stages that the health-based risk of the project may need to be quantified.

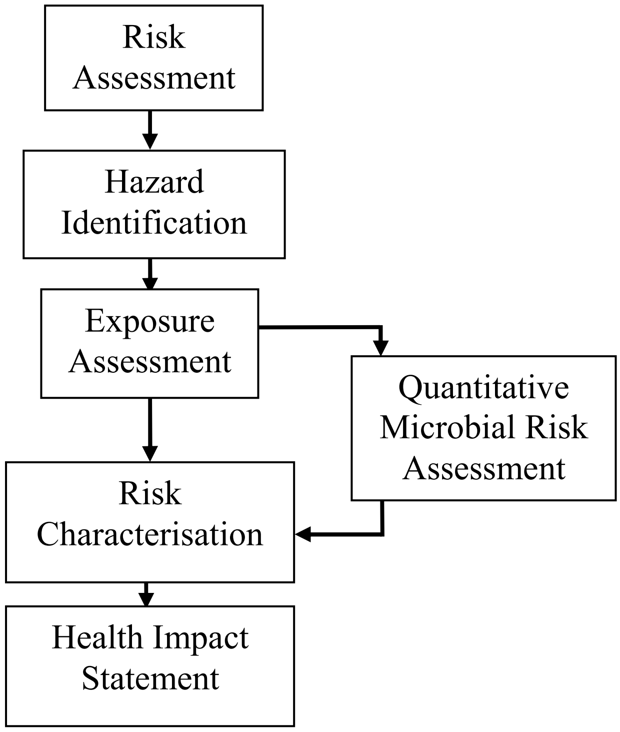


Figure 5.25 The HIA Procedure (adapted from Fewtrell and Kay, 2008)

5.5.1 Quantifying a Health-based Risk

In conducting HIAs both qualitative (subjective plus or minus scores on a linear scale, such as (- -) or (+ +)) and quantitative measures are used (Fewtrell and Kay, 2008). In order to quantify a health risk, a numerical value is required to provide an objective and standardised risk value that permits comparison across various scenarios. Two health measures that have previously been used to represent the risk posed by hazards include the Years of Life Lost (YLL) through disease burden or death and the Years Lived with a Disability (YLD). The combination of these measures has resulted in a more comprehensive risk quantification measure or score, which is termed the 'Disability Adjusted Life Year' or DALY (Fewtrell and Kay, 2008). This uses the probability of exposure to a hazard to calculate the number of years a person or group will be affected by disability (due to injury, illness or other health impact) as a proportion of their life expectancy.

The YLD aspect permits inclusion of injury and illness, as non-fatal incidents may be more likely to occur in relation to some programmes or projects. The life expectancy at birth used for such analyses will depend on the country within which the HIA is being applied. Within a DALY score these measures are combined and normalised with severity or disability weightings, ranging from death (0) to perfect health (1). Fewtrell and Kay (2008) suggest that a suitable DALY screening level for the impact of a risk on health is 5×10^{-5}, which equates to 0.00005 years of life affected by disability. To place this into context, the *average* DALY score for being struck by lightning is 2.1×10^{-6}, which is a lower number of years of life affected (of course in reality this will not be evenly distributed throughout the population as someone may be struck and die, receiving a DALY score of their life expectancy minus their age at death). Fewtrell and Kay (2008) highlight that the designation of an 'acceptable' DALY (i.e. a tolerable health impact) is entirely political (not based on any particular health criteria).

5.5.2 HIA and RWH

RWH and HIAs are innovative and relatively new techniques (in the context of application within the SWM sector) and previous studies are limited, in both the scale of system to which they are applied and the FIOs they consider. For example, an Australian study by Chapman *et al.* (2006), considered health-related impacts from RWH systems. However, they did not apply a structured framework or methodology for risk assessment, such as a HIA, to quantify the significance of potential RWH system impacts. Even where a formal HIA was applied (Maxwell and Thornell, 2009) to an Australian site (a hospital) within which RWH was to be potentially located, quantification of the risk from the system to relevant parties was not included. However, a recommendation of the HIA was that such systems should be subject to appropriate risk assessment and management inline with New South Wales health guidelines to prevent illness in immuno-compromised patients or visitors (those with weakened immune systems).

In contrast, the UK is at the vanguard of HIA adoption and usage, with approximately a quarter of reviewed published studies being undertaken within the UK. Additionally, UK-based research is at the forefront of the application of HIA to SWM and RWH (Fewtrell and Kay, 2008). A particularly noteworthy UK-based study includes Fewtrell and Kay (2007b), which included a QMRA within a HIA of *Campylobacter* spp. of a development of 1868 standard domestic RWH systems. This is extended in Fewtrell *et al.* (2008) to cover all potential risks from RWH system installation, operation and maintenance (such as falling off ladders whilst cleaning catchment areas etc). A further study by Fewtrell *et al.* (2009), conducted a HIA of *Campylobacter* spp. in an experimental innovative RWH system installed on three office buildings.

The DALY scores derived in these studies are summarised in Table 5.7. These are summarised along side the suggested screening level identified in Section 5.5.1, the score for a lightning strike and the WHO tolerable disease burden for drinking water (Fewtrell and Kay, 2008), for comparison. It can be seen that the DALY scores for the RWH studies are generally in the region of the screening level, but are higher than the lightning strike score, indicating the number of years affected by illness or injury from using a RWH system is marginally higher than from being struck by lightning. The DALY scores of the RWH studies are much lower than the WHO score, indicating the risk posed by drinking the harvested rainwater does not exceed the recommended level.

Table 5.7 Summary of DALY scores for UK RWH system studies, the suggested screening level, WHO level for drinking water and a lightning strike

Study/Incident	DALY	DALY A*	DALY B*
Fewtrell and Kay (2007b)	6.8×10^{-5}	5×10^{-5}	4.5×10^{-3}
Fewtrell and Kay (2007b)	7.4×10^{-5}	5×10^{-5}	4.5×10^{-3}
Fewtrell *et al.* (2008)	4.59×10^{-4}	5×10^{-5}	4.5×10^{-3}
Fewtrell *et al.* (2009)	2.96×10^{-6}	5×10^{-5}	4.5×10^{-3}
Lightning strike (Fewtrell and Kay, 2008)	2.1×10^{-6}	5×10^{-5}	4.5×10^{-3}

A* = suggested screening level (Fewtrell and Kay, 2008); B* = WHO (2004) tolerable disease burden from drinking water (from Fewtrell and Kay, 2008)

Discussion of these studies highlights that although HIAs of general and microbiological hazards have been undertaken for UK-based RWH systems, the FIO *E. faecalis* has not previously been subject to a HIA or QMRA. Sections 5.3 and 5.4 of this chapter identified that *E. faecalis* levels were consistently higher that the recommended guideline levels in the British Standard. Therefore in the sections that follow, a HIA with QMRA is undertaken for the Innovation Centre RWH system, to determine the health risk posed to its occupants by flushing WCs with harvested rainwater.

5.5.3 HIA of the Innovation Centre RWH System

5.2.1.1 Risk Assessment

The risk assessment first considers the health and age characteristics of the population (group of individuals) affected by the project in question, as well as the features of the project likely to cause a hazard. For the Innovation Centre population of 111 individuals (Jackson, 2009), results from Chapter 3 are utilised. Although the questionnaire at the centre of this chapter was not completed by every building occupant, it provides a reasonable estimate of the likely age structure of building occupants, which are summarised in Table 5.8. No health-related data were collected as part of the questionnaire. However, as the population consists of a workforce, the assumption is made that 90% of the population classified their health as good. It is also assumed that the number of children (<16), the elderly (70+) or immuno-compromised individuals using the building is negligible (i.e. zero). The life expectancy at birth is taken to be the UK life expectancy, which is 78 years (Fewtrell and Kay, 2008).

Table 5.8 Age profile of the Innovation Centre study population

Age group	% of sample population	Age group	% of sample population
Under 20	5	41-50	5
21-30	37	51-60	11
31-40	42		

The following features of the Innovation Centre building and RWH system are considered within the following hazard identification exercise.

- RWH system – single pressurised system in an office building;
- Dual-face roof catchment;
- Underground storage tank;
- Two in-building header tanks;
- RWH system use – WC flushing only;

- Installation – previously completed by external contractors;
- Operation – provided by external contractors;
- Maintenance – provided by external contractors.

5.2.1.1 Hazard Identification

The Innovation Centre RWH system receives operational support from a Buildings and Estates Department. In addition to this, an external RWH system manufacturer and supplier provides the system maintenance. Therefore no operation or maintenance activities are conducted by building occupants, reducing risks from drowning or injury-related hazards, for example falling off ladders whilst cleaning gutters. Fewtrell *et al.* (2008) highlight that the provision of these professional support services can result in additional health benefits to building occupants, which helps to reduce DALY scores.

With regards to infection, however, the situation may be different. As previously discussed, Section 5.3.2 identified the numbers of *E. faecalis* in harvested rainwater from the Innovation Centre RWH system were in excess of the recommended British Standard guideline value. Therefore it could be hypothesised that there is a potential risk to building occupants from flushing a WC with water with high *E. faecalis* numbers. Harvested rainwater can contain a range of other bacteria and protozoa, including *Campylobacter* spp., *Salmonella* spp. and *Cryptosporidium* spp. The latter two pathogens were not observed in samples from the IC system and *Campylobacter* was not tested for, therefore these pathogens are not considered further in this HIA. Ideally, the potential impact of elevated E. *faecalis* counts should have been identified before the building or system was designed, but at present it is very rare for a HIA to be undertaken for RWH systems. However, retrospective analysis has established that there is a risk posed that is worthy of further investigation.

A further potential hazard posed by the use of a RWH system is *anxiety* – originating from visible deposits, smells, unfamiliarity with these and/or their perceived health effects. Chapter 3 outlines results of a questionnaire undertaken with IC staff that used the WCs flushed by the RWH system. Within this questionnaire, data was gathered on the participant's experiences with and perceptions of WC cleanliness, smell and colour. Participant's responses and comments established that there were observed colour, smell and cleanliness differences (to a WC flushed with mains water), which had the potential to cause concern. Therefore using the qualitative hazard assessment scale (outlined in 5.5.1) a qualitative estimate of (-) is designated for the RWH system, to indicate a possible minor negative health impact from anxiety.

5.2.1.1 Exposure Assessment

As outlined above, the provision of external RWH system operation and maintenance services results in almost no exposure to hazards presenting the possibility of building occupants drowning/near-drowning or sustaining injury. Therefore exposure to these hazards will not be considered further in this HIA. It should be noted, however, that the situation may be different where in-house maintenance of a RWH system is provided.

A potential hazard resulting from exposure to *E. faecalis* has been identified. Exposure routes with the potential to cause infection are well established (Fewtrell *et al.*, 2008). These are inappropriate ingestion/contact, inhalation, ingestion of contaminated items and vector-borne (distributed by an organism). The Innovation Centre RWH system is only used to flush WCs; there is no external tap provided for any outside use and the plumbing from the header tanks is specific to the WCs. The system was checked by the building construction company/system installer and also commissioned by the supplier. It is therefore unlikely that any cross-connection has occurred. System monitoring data (Chapter 6) further reinforces this, as (after resolution of some issues) the system appears to be operating as expected i.e. rainwater is primarily being used, rather than mains water. If the opposite was occurring and rainfall in the area was normal and no system faults were reported, higher mains consumption could be indicative of a cross-connection. In light of these factors, the main exposure risk that will be considered is that of aerosols from the WC pan during/after flushing. In order to quantify the risk to health posed by exposure to this hazard, a QMRA was performed.

5.2.1.1 Quantitative Microbial Risk Assessment

As described in Section 5.5, a QMRA requires dose-response relationships and probability of exposure calculations to be undertaken. Empirical studies on the dose-response relationship between ingestion, infection and illness have not been undertaken for *E. faecalis*. One study, upon which the British Standard RWH guideline value for *E.*

faecalis is based, did measure the exposure of fully-submerged recreational bathers to *E. faecalis*, but a dose-response relationship was not determined (Kay *et al.,* 1994). These exposure conditions highly contrast likely exposure from WC flushing by RWH, as these are likely to be minimal spraying with an aerosol.

Concentrations of *E. faecalis* are heavily site specific. Horak *et al.* (2010) measured *E. faecalis* levels in all RWH tanks examined in a study in Papua New Guinea. In other literature where *E faecalis* was tested for, it was present (albeit at varying levels) in 11 out of 12 studies (Ahmed *et al,*. 2008; Birks *et al.,* 2008; Hollander *et al.,* 1996; Horak *et al.,* 2010; Jordan *et al.,* 2008; Lye, 2002; May and Prado 2006; Sazakli *et al.,* 2007; Schets *et al.,* 2010; Simmons *et al.,* 2001; Uba, 2000 (from CRC, 2005)).

In light of the occurrence of *E. faecalis* in previous studies and the levels at which it is found in the present study, it was decided to use a dose-response relationship for a bacteria with similar prevalence characteristics. The well established dose-response relationship for *Campylobacter* spp. (Fewtrell and Kay, 2008) was utilised, which takes the form of a Beta Poisson model. This model calculates the probability of becoming infected by ingesting a dose of an organism, using alpha and beta parameters, representing the random probability of any one organism causing infection. The probability of exposure was calculated using the concentration of *E. faecalis* in the harvested rainwater, the volume of WC flushing aerosol ingested (taken from Fewtrell and Kay, 2008) and the number of flushes per person per day (for the Innovation Centre, derived in Section 6.4.7). Urinals were not considered, as these are waterless in the Innovation Centre. Other assumptions used included an even distribution of *E. faecalis* in the water column and a consistent daily exposure. Weekends were not included (as the building is assumed to be empty) and the number of days exposed reflects this (365-104). Sick and holidays were not considered in the analysis as these are confidential records and were not available.

The dose-response and the probability of infection calculations resulted in the calculation of a probability of illness. This was combined with a severity weight (representing the impact of the illness) and duration (the length of the illness), for the previous *Campylobacter* spp. study, to yield a DALY score for the hazard posed by ingesting *E. faecalis*. The resulting dose-response and probability of exposure values are summarised in Table 5.9 and the calculations are located in Appendix E.

Table 5.9 QMRA data requirements for calculating the DALY for *E. faecalis* via WC flushing

Data requirement	Source	Value
E. faecalis concentration	Present study	2/ml
Water volume ingested/contacted	Fewtrell and Kay (2008)	0.2ml
Dose per flush	Calculated*	0.368
Exposure frequency	Fewtrell and Kay (2008)	5%
Number of flushes per person/day	Present study	3
Daily exposure frequency	Calculated*	0.15
Dose per day	Calculated*	0.055
Dose-response relationship parameters	Fewtrell and Kay (2008)	Alpha = -0.145
		Beta = 7.589
Dose-response	Calculated*	0.999
Daily probability of infection	Calculated*	0.001
E. faecalis contamination frequency	Present study	37%
Annual contamination frequency (days)	Calculated*	95.49
Annual probability of infection	Calculated*	0.1
Probability of illness	Fewtrell *et al.* (2008)	0.3
Annual cases of illness	Calculated*	3.34
Severity weight^	Fewtrell *et al.* (2009)	0.093
Duration^	Fewtrell *et al.* (2008)	6 days

* = located in Appendix E; ^ for uncomplicated gastroenteritis

It is standard practice to apply a Monte Carlo (sensitivity) analysis within a QMRA in order to consider uncertainty in the range of parameter values possible in the calculations and obtain minimum, mean and maximum DALY scores. This was conducted using the risk analysis tool '@Risk' (Palisade, 2010) to selected parameter values, inline with Fewtrell and Kay (2008). Within @Risk distributions were assigned to the parameters summarised in Table 5.10 and a range and mean values were defined. @Risk was then used to sample parameter values from the assigned distribution to calculate the required DALYs. The resulting minimum, mean and maximum DALY scores are summarised in Table 5.11 in the following section, where they are discussed.

Table 5.10 @Risk input values

Parameter	Distribution	Mean	Range
Volume ingested (ml)	Normal	0.1	0-0.2
E. faecalis Concentration (no/ml)	Log Normal	0.09	0-2
Frequency of contamination	Normal	5	0-15
Number of flushes	Discrete	NA	1-3

5.2.1.1 Risk Characterisation

Table 5.11 summarises the hazards identified for the Innovation Centre RWH system and their risk given qualitatively or quantitatively. Also shown are DALY scores from other RWH studies as comparators, as well as the screening level and WHO level discussed in Section 5.5.2. It can be seen that the mean risk posed by flushing a WC containing *E. faecalis* from the RWH system is (a) comparable to that identified for other microbial species from previous studies; (b) in the region of the suggested screening level and (c) less than the WHO score, indicating that the risk posed by drinking the harvested rainwater is within the recommended level. However, it is marginally higher than the lightning strike score, indicating the number of years affected by illness or injury is marginally higher than from being struck by lightning.

Table 5.11 Risk characterisation summary for the Innovation Centre RWH system with comparators

Hazard	Exposure		Impact/DALY
Mental health	Anxiety		(-)
Illness	*E. faecalis* from WC flushing	Min	2.25×10^{-7}
		Mean	$\mathbf{1.80 \times 10^{-5}}$
		Max	2.15×10^{-4}
Illness	*Campylobacter* spp. from WC flushing with an innovative RWH system (Fewtrell *et al.,* 2009)		2.96×10^{-6}
Illness	*Campylobacter* spp. from WC flushing with a standard RWH system (Fewtrell *et al.*, 2008)		4.6×10^{-5}
Illness	*Campylobacter* spp. from WC flushing with a standard RWH system (Fewtrell and Kay, 2007b)		6.8×10^{-5}
Illness	WHO (2004) for drinking water		4.5×10^{-3}
Illness	**Suggested Screening Level (Fewtrell and Kay, 2008)**		$\mathbf{5 \times 10^{-5}}$
Lightning strike	(Fewtrell *et al,*. 2009)		2.1×10^{-6}

The risks quantified are additive, as each represents a severity and duration for the DALY. Therefore multiple exposure to different hazards/risks would result in an increase in exposure and consequently the DALY score.

5.2.1.1 Health Impact Statement

From the results of the HIA and QMRA, it is clear that the health risk posed to building occupants from the RWH system is of an acceptable level, when compared with other hazards. Therefore it can be asserted that even a RWH system with inappropriate building and roof design and no first flush control device exhibits no more health based risk than the suggested screening level. RWH systems implemented using a more carefully considered process should therefore present an even lower risk. This provides reassurance of RWH as a safe source of water for non potable uses such as WC flushing. Investigation of the other uses that people would consider acceptable (as identified in chapter 3) is required to obtain DALY scores for these. The result of the HIA undertaken, as well as previous HIA results for RWH systems, indicates that greater awareness raising activities are required in order to dispel the myth that RWH posses a significant health risk.

5.6 Chapter Summary and Key Messages

This chapter has presented the results of a long-term monitoring programme into the harvested rainwater quality of a RWH system in an office building. It has been identified that the variability of harvested rainwater quality was influenced by local factors. This included the possible contribution of airborne deposition of chloride and bacteria from local sources. The most significant local factor influencing quality, however, was the design and construction of the building, roof and surface drainage infrastructure for the building within which the RWH system was situated. Physicochemically, comparison with WHO guidelines revealed that parameters presented limited health hazard. However, soft water corrosion potential was identified in relation to internal metal fittings and external metal pipe work, resulting in relatively high concentrations of some metals. Although these observations were based on a limited number of samples, they suggest the material selection of such fittings should be considered keeping in view the hardness of rainwater of the area in which a system is to be located. Further study into the concentrations of these metals within the storage tank sediments is required, in order to assess potential issues with sediment disposal.

Microbiologically, *Salmonella* and *Legionella* were not present in the samples analysed and minimal occurrence of *Cryptosporidium* was observed. However, *E. faecalis* counts were consistently above guideline levels, suggesting a potential hazard. Further analysis of antecedent weather conditions highlighted that elevated *E. faecalis* (and other parameter) values correlated to longer dry periods prior to a rainfall event. A HIA of the system, with respect to *E. faecalis* revealed an average DALY score of 1.80×10^{-5}. This demonstrates that although inappropriate building and RWH system design features compromised the harvested rainwater quality – in relation to British Standard guideline values – the overall health risk was minimal. Greater awareness is required to dispel the myth that RWH posses a significant health risk and to reassure both owners and users of systems.

Inappropriate roof, rainwater system goods and surface drainage design, as well as material selection were responsible for reduced microbial quality, as they promoted contributions from avian sources (by facilitating roosting) and inhibited cleaning activities. Omission of a first flush device, which could remove heavily contaminated volumes of runoff, from the system should be addressed to help improve the quality of harvested rainwater within RWH system. Further research is required into the use of first flush devices in the UK, as they are currently omitted from the British Standard. Building and RWH system design are therefore critical in establishing and maintaining good harvested rainwater quality and preventing both the development of contaminated sediments and health impacts.

The key messages from this Chapter are:

(1) Awareness needs to be raised regarding the importance of building and roof design and construction in relation to RWH system implementation;

(2) A potential contaminant flushing effect was inferred using statistical analysis, for certain parameters, suggesting greater consideration may need to be given to first flush devices in the UK;

(3) Application of a HIA identified that the health risk posed to occupants flushing WCs with RWH in an office building is minimal and politically acceptable;

(4) Activities to raise awareness of this minimal risk need to be undertaken and quantification of results more widely disseminated.

The chapter research questions posed at the beginning of the chapter have been answered as follows:

- What impact do physicochemical parameters have on RWH system function?

The main potential impact observed in relation to the Innovation Centre RWH system was the potential corrosion of metals due to the softness of the harvested rainwater. However, further sampling would be required, including of tank sediments, to determine sources of the metals and permit statistical analysis.

- What is the health risk associated with flushing WCs with RWH?

In light of the results of the harvested rainwater quality monitoring programme described in this chapter, along with those from previous studies, it is concluded that the health risk posed by flushing WCs with RWH is within the tolerable disease burden acceptable from drinking the harvested rainwater and therefore acceptable.

The following chapter builds on the contribution of this chapter to the technical evidence base, by undertaking an assessment of the design and performance of the Innovation Centre RWH system.

6 CHAPTER 6: UNDERSTANDING RWH SYSTEM PERFORMANCE – DESIGN AND PERFORMANCE EVALUATION

6.1 Introduction

Objective three of the research is to enrich the technical (and social) knowledge base relating to RWH in the UK. The previous chapter focused on the water quality of the rainwater harvested by an office-based RWH system. This chapter builds on this by addressing the following technically-orientated research questions identified during the literature review:

- How do system design methods perform in comparison with empirical data?
- How does an office-based system perform in terms of water saving efficiency?
- What are the energy consumption and carbon emission implications of systems?
- Are non-domestic demand parameters adequately represented within system designs?

An office-based RWH system was chosen as a case study to examine these research questions for two main reasons. Firstly, the majority of research conducted on RWH systems in the UK has been at the household scale. In contrast to this, the greatest opportunity to implement RWH (for both financial and sustainability reasons) is arguably within the SME sector. Secondly, a system was being implemented within an office-building on the University of Exeter campus, thus providing an excellent opportunity for a detailed study of both implementation and operation.

This chapter is divided into three main sections:

- **RWH System Design Evaluation;**
- **RWH System Performance Evaluation;**
- **Non-domestic WC Demand Profiling with RWH System Design Comparison**

The first section is concerned with the evaluation of two new build RWH systems: the previously mentioned communal systems within the Broadclose development and the Innovation Centre (IC) office-based system (Chapter 3). This is followed by a section describing the monitoring programme and empirical data analysis activities undertaken for the Innovation Centre system, which provides a comparison with the design evaluation. Unfortunately a parallel assessment of the actual performance of the systems at Broadclose could not be undertaken, due to a lack of data available for the site. This resulted from inadequate implementation of a monitoring programme by the development's management organisations. Meters were installed in 7 of the 173 houses, but were not read regularly due to changes in company personnel, lack of liaison with homeowners and an apparent lack of interest in the data.

The author was unable to directly implement an independent programme for reading the meters due to their location within residents' houses (the tenure of which varied). This section also describes an improved method by proxy (using harvested rainwater volume pumped data) for calculating the energy consumption and CO_2 emissions from RWH system pumping activities and is applied to the empirical data collected. The third section describes the design and implementation of a flush counting device, which was utilised to quantify non-domestic WC demand within the Innovation Centre. This section also covers the analysis of the resulting data, its comparison with the well established domestic WC demand profile and the utilisation of the non-domestic profile within a RWH system design comparison.

6.2 RWH System Design Evaluation

As established in the literature review (Chapter 2) there is a number of tools available for designing RWH systems and in particular for sizing the storage tank. Three methods are used within the design evaluation, two of which are based on the approach developed by Fewkes (1999b), which built on an original concept devised by Jenkins *et al.* (1978). The core of this approach is a water mass balance in the form of Equation 6.1

$$V_t = V_{t-1} + Q_t - D_t \qquad \textbf{Equation 6.1}$$

Subject to $0 \leq V_t \leq S$

Where:

V_t = (Rain) Water in storage (m^3) at end of time interval, t

Q_t = Inflow (m^3) during time interval, t

D_t = Demand (m^3) during time interval, t

S = Storage capacity (m^3)

From this the 'yield-after-spill' and 'yield-before-spill' (YBS) operating rules were developed (Fewkes and Butler, 2000), which take the form (for YAS and YBS respectively):

$$Y_t = \min\begin{cases} D_t \\ V_{t-1} \end{cases} \qquad V_t = \min\begin{cases} V_{t-1} + Q_t - Y_t \\ S - Y_t \end{cases}$$

Equation 6.2

$$Y_t = \min\begin{cases} D_t \\ V_{t-1} + Q_t \end{cases} \qquad V_t = \min\begin{cases} V_{t-1} + Q_t - Y_t \\ S \end{cases}$$

Equation 6.3

Where:

Y_t = Yield from store (m^3) during time interval, t

The YAS and YBS rules determine the position of supply, demand and overflow in the calculation of storage volume. Fewkes and Butler (2000) undertook extensive analysis of the YAS and YBS algorithms which led to the derivation of capacity-demand and catchment-rainfall ratios (called the demand fraction and storage fraction, respectively. From this research it was concluded that the YAS operating rule (with an hourly or daily rainfall time series) provided the most accurate, conservative results.

Fewkes (1999b) and Fewkes and Warm (2000) extended this work and developed a set of generic performance (water saving efficiency, E_T) curves for RWH in the UK. They also established a mathematical relationship for establishing a suitable tank size; an input ratio for the desired RWH system is calculated using AR/D, where A is catchment area (m^2), R is average annual rainfall (mm) and D is average annual demand (m^3). This is used to locate a desired performance level (water saving efficiency, E_T) and the number of days storage (X) from design curves. The tank size can then be calculated using Equation 6.4.

$$S = X.D_d$$

Equation 6.4

Where:

X = Number of days storage

D_d = Average daily demand (L)

Within the present study, Method 1 is based on the YAS approach in the form of a continuous simulation which can utilise daily rainfall and demand time series, representing the state-of-the-art in UK-based RWH system design. Method 2 is a simplified version of the AR/D approach, which simply takes a user-defined number of days storage (rather than being selected using the AR/D ratio) and multiplies it by an average daily demand. Current best practice recommends that a dry-weather (i.e. a period without rainfall) supply volume equal to six days of demand should be used for the UK, as it is unusual to exceed six days without rainfall (Leggett *et al.*, 2001). For example, if daily demand is $1m^3$, the tank should be $6m^3$. This approach was used when applying Method 2.

The final method, Method 3, is based on a different approach recommended by the Environment Agency (EA) (2008). This is a simple 'rule-of-thumb' method, which sizes the tank based on a user-defined percentage of average annual rainfall or demand (whichever is the lower). The equation for this approach takes the form of Equation 6.5.

$$S = P.A.C_f.F.R \qquad \textbf{Equation 6.5}$$

Where:

P = User-defined percentage (current best practice recommends 5%, i.e. 0.05)

C_f = Runoff coefficient

F = System filter efficiency

A and R are as previously defined.

(R would be replaced by D if the annual demand was the lower of the two).

However, the application of this approach is recommended for smaller RWH systems only, such as domestic systems, as larger systems require a more rigorous analysis due to the complexity of demand patterns (EA, 2008b).

Analyses were undertaken using an Excel/VBA-based modelling tool, RainCycle (Roebuck and Ashley, 2007). This tool implements the above three methods. Within Method 1, the tool optimises a predicted tank size based on inputs such as rainfall and demand level, to provide a balance between the estimated percentage of demand met and potential financial savings in relation to capital cost. Method 1 also includes the facility to calculate the whole life cost, payback period and cost-benefit of a RWH system (with mains top-up) in comparison with an equivalent mains water supply. The outlined methods and tool were utilised within the current study, rather than more academically orientated methods and tools, as they are currently easily accessible (public domain) to those who would be involved in RWH system designs (suppliers, architects and so on). In addition, synthetic or long-term rainfall time series were not used, as these would not necessarily be readily available to stakeholders.

6.2.1 Approach

The three previously described methods were used to calculate tank sizes for two case study developments. This was done in order to compare calculated tank sizes with the actual tank sizes designed and installed by RWH system suppliers. As previously mentioned, the modelling tool utilised also permits whole life cost and cost-benefit analyses. However, as the RWH systems assessed within this study were within new developments, no operating costs had been accrued at the time of writing. Furthermore, expected maintenance regimes and their associated costs were not available at the time of analysis. For these reasons no whole life cost analyses could be performed. This was unfortunate as the literature review identified financial aspects were also a significant knowledge gap. In order to include financial aspects as far as possible, capital cost information was used; being £15,500 per system (storage tank plus associated piping, pumping and controls, *not* including installation costs), which was used within Method 1 analyses to yield a payback period for both sites. Further research, possibly involving maintenance document analysis on well-established systems, would help to address the financial knowledge gap.

In addition, a cost-benefit analysis is given (using capital costs only), by comparing the *financial* savings of using a RWH system (plus mains-water top-up) with only using the mains water supply (a default function of the modelling tool). Savings (£) per year indicate the potential financial savings made by using rainwater via the RWH system, compared to the cost of supplying water via the mains water supply. Water supply and sewerage charges are held within the modelling tool, which are used to calculate annual mains costs based on the input demand data. Savings are then calculated using these figures in comparison to the volume of RWH utilised to supplement mains water. For whole life costs, a net present value (NPV) discounting approach is used, which is applied across the length of the simulation. As the financial analysis within this section does not include whole life costs (maintenance, decommissioning etc), the algorithms used to implement these steps are not covered in detail (see Roebuck (2008) for details). Within the Method 1 continuous simulations, an analysis period of 25 years was used, as this duration is often quoted as being the minimum expected lifespan of RWH system tanks and components (Pushard, 2004; WPL, 2007).

6.2.2 Site Characteristics

6.2.2.1 Site 1: Broadclose

The Broadclose housing development is located near Bude in Cornwall, south-west England, and is a new-build project involving The Guinness Trust, North Cornwall District Council, the Westcountry Housing Association and Midas Homes Ltd. The need for water efficiency measures was considered right from the beginning of the design and planning phases and the homes currently achieve the EcoHomes 'very good' rating; EcoHomes is the domestic dwelling equivalent of the BREEAM (BREEAM, 2007). Broadclose contains 173 homes divided across 13 'home zones' (HZ), each of which has a communal RWH system, collecting runoff from south facing roofs, which is used for WC flushing. Additional site characteristics are summarised in Table 6.1. The mix of housing types within a particular HZ varies, but can include 1-bed flats, 2/3/4-bed houses and 2/3-bed bungalows. Consequently, the main storage tank for each HZ is a different size; runoff collected and demand experienced will vary depending on total roof catchment area and HZ occupancy.

6.2.2.2 Site 2: Innovation Centre

The Innovation Centre on the University of Exeter's Streatham campus is an office building, which achieved the BREEAM 'Excellent' rating. The single RWH system within the building is used to supplement mains water and supplies WCs via a large underground storage tank and two header tanks. Additional site characteristics are summarised in Table 6.1. Please refer to Chapter 3 for location maps and Chapter 5 for photographs of the building and system components. The building is occupied by a range of businesses (approximately 111 permanent individuals), with café and conference facilities, which operate during office working hours. It is divided into two wings – East and West – along with a central area in which the café and conference suite are located.

Table 6.1 Characteristics of Site 1 and Site 2

	Units	Site 1	Site 2
Type of development		Housing development	Office building
Size (approx occupancy)		415	300
Type of system		Communal	Single site
Use of RWH system		WCs (toilets)	WCs (toilets)
Standard average annual rainfall (30-year) near site	mm	881 (Bude)	807 (Exeter)
Total (roof) catchment area	m^2	3893 (22.5/property)	1500
Roof catchment characteristics		Pitched, tiled	Flat, smooth
Total storage tank volume	m^3	255.5	25
Average daily demand	m^3	19.92 [a]	5.19 (working day) [a] 0.36 (holiday) [a]
Total yearly demand	m^3	7270 [a]	1353 [b]

a = calculated within RainCycle; b = calculated by RWH system supplier

6.2.3 Site 1: Design Evaluation

The communal RWH systems within Site 1 were designed and supplied by a second RWH system supplier, again using an adaptation of Method 2. A complete set of the parameters used in the supplier analysis was not available and thus some, such as demand, were calculated by the author. These are summarised in Table 6.2.

Construction of Site 1 was completed in August 2008, but occupancy figures were not available at the time of the analyses. It was therefore decided to use the average household occupancy rate of 2.4 (DCLG, 2006b), leading to a total occupancy of 415. A WC volume of 6L was used (as 6L flush WCs are now fitted to new homes as standard), along with an average flush rate per day per occupant of 8 (the recommended value within RainCycle). This led to the estimated annual demand figure of 7270m^3. Other demand scenarios could have been examined, such as a combination of single or full flushes, but this was beyond the scope of the present study as such scenarios were not investigated by the supplier. A monthly 30-year standard average (1961-1990) rainfall profile was obtained for Bude (Met Office, 2007), which has an annual total of 881 mm. As runoff is only collected from south facing roofs, the average per property roof size

(45 m^2, derived from site plans) was halved and then multiplied by the number of properties (173) to yield an approximate total catchment area.

Table 6.2 RWH system supplier design parameters and author calculated values for Site 1

Parameter	Units	Value used by RWH system supplier
Total local rainfall (annual)	mm	881*
Roof area	m^2	3893*
Occupancy		415*
Estimated annual demand	m^3	7270*
Days required storage		6.8
Demand days		365
Filter coefficient		0.9
Runoff coefficient		0.85
Run duration	years	25

* calculated by author

An initial simulation was carried out using the values for the development as a whole (rather than by HZ). Method 1 results revealed that 36% of the WC demand would be met using RWH, yielding an average annual saving of £756 (compared to the mains water supply) or £4.37 per property, with a payback period of 23 years. No yield or financial data was provided by the supplier for this site, so no comparison could be made. Furthermore, Method 1 indicated the available storage (255.5 m^3) was not fully utilised, being empty on a large number of days and recommending a total storage capacity for the development of 12 m^3. Method 2 and Method 3 calculated tank sizes were 120 and 131 m^3, respectively, demonstrating their use for large scale systems is limited, as recognised by the EA (2008).

6.2.3.1 Catchment Area Limitations

A limiting factor in meeting demand appeared to be the size of the roof catchment area utilised. Using both north and south facing roof faces within Method 1 indicated that 72% of demand could be met with a revised tank size of 34 m^3. This could yield average annual savings of £9,571, or £55 per property, with a payback period of 11 years. Method 2 and Method 3 yielded tank sizes of 120 and 262 m^3, respectively, for the increased catchment area, which are in line with the actual total capacity. The figure for Method 2 does not change, as the method only uses the number of days storage; it does not account for changes in catchment area size.

Method 1 indicated the overall tank volume to be substantially over-sized. Nevertheless, a potential (but as yet empirically unproven) benefit of over-sizing storage tanks is the availability of extra storage capacity to reduce runoff during periods of heavy rainfall (depending on the design of and demand on the system permitting an adequate airspace to be available prior to a rainfall event). This could prove beneficial in relation to climate change; projections indicate an increase in winter (already some of the wettest months) precipitation of between 5 and 15% (SWCCIP, 2003). This would complement other SUDS techniques in use at Broadclose, such as swales and surface ponds.

To further explore the level of savings and to investigate the sizing of individual HZ storage tanks, the methods were applied separately to each HZ. These simulations used individual tank sizes and calculated the occupancy and catchment area based on the number of properties within each HZ. Table 6.3 summarises the tank sizing comparison results for each method for each HZ, along with the associated financial savings.

The total volume previously calculated for the whole development using Method 1 was $12m^3$, yet the aggregate of the 13 individual HZs tank size analysis is $30m^3$. Furthermore, there is a substantial difference between the actual implemented tank sizes and those calculated using the three methods. Tank sizes calculated using Method 1 are between 200% and 600% smaller than those calculated using Methods 2 and 3. It should be noted that had the number of days storage used within Method 2 been increased, tank sizes calculated would have also been higher (perhaps closer to the actual tank sizes installed). A comparison of actual total tank size and those calculated using the various methods is summarised in Figure 6.1, which also illustrates capital cost proportionally as the circle size. Figure 6.1 shows that the installed tank capacity is substantially in excess of those estimated by any of the methods, increasing the capital cost substantially. The consistency in the estimates using method 1 indicates this method may be the most appropriate.

It was also identified that although the same annual financial savings were achieved, the distribution of the savings was highly variable across the HZs; some sustaining annual savings of £451 and others *losses* of £263 (compared to the mains-only water supply).

Table 6.3 Comparison of results for each home zone (HZ) in Site 1 using each method

HZ #	% Demand Met	Payback Period	Savings £/year	Catchment area	Actual tank size	Method 1 tank size	Method 2 tank size	Method 3 tank size
Units				m^2	m^3	m^3	m^3	m^3
1	36.4	19	195	360	27	2	10.9	12.1
2	36.4	14	451	472.5	22.5	3	14.4	15.9
3	35	N/A	-9	270	22.5	2	8.4	9.1
4	35.8	16	349	427.5	27	3	13.2	14.4
5	36.1	15	399	450	22.5	3	13.8	15.2
6	35	N/A	-161	202.5	15	2	6.3	6.8
7	35	22	93	315	17.5	2	9.8	10.6
8	36.4	N/A	-213	180	15	2	5.5	6.1
9	35.8	N/A	-9	270	17.5	2	8.4	9.1
10	36.4	N/A	-213	180	15	2	5.5	6.1
11	36.4	N/A	-213	180	12	2	5.5	6.1
12	35.8	N/A	-263	157.5	15	2	4.9	5.3
12b	35.8	16	349	427.5	27	3	13.2	14.4
Total			**755**	**3892.5**	**255.5**	**30**	**119.8**	**131.2**

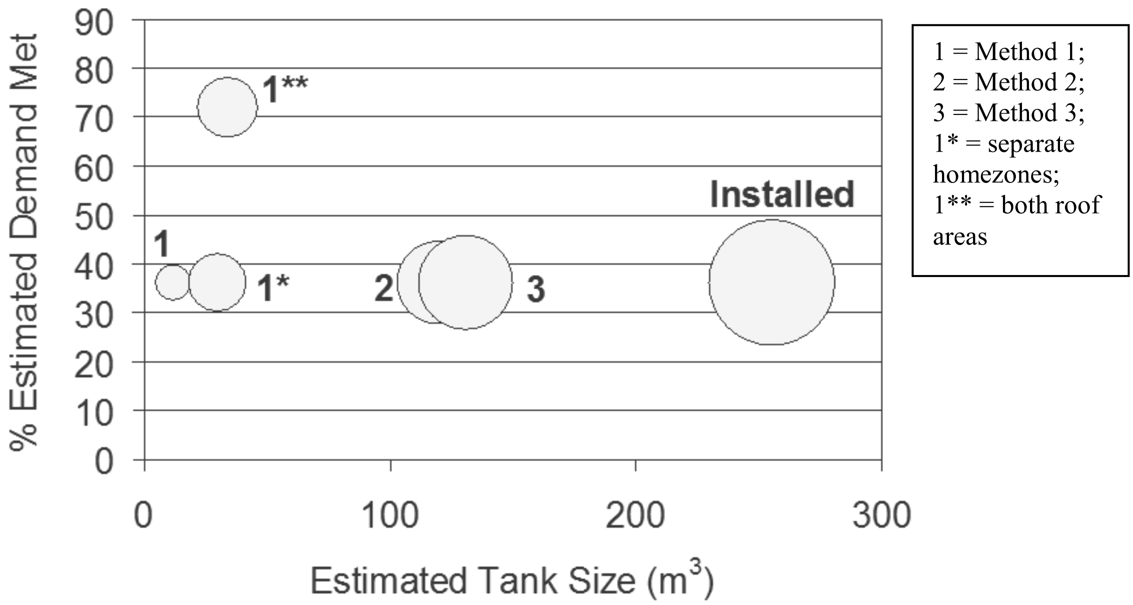


Figure 6.1 Differences in actual and estimated tank sizes, for Site 1

6.2.4 Site 2: Design Evaluation

The RWH system was supplied by Stormsaver, a UK-based supplier. An Excel tool based on the AR/D approach (Method 2) was used by the supplier to design the system. The tool uses parameters including local *annual* rainfall (based on a Met Office 40 year figure), roof area, estimated *annual* demand, number of days required storage, filter and runoff coefficients and system efficiency. The parameter values used in the RWH system supplier design are summarised in Table 6.4. Although the system manual quotes the pre-tank filter as being able to achieve 95% efficiency, the figure used in the design was 90%, so this has been used in the simulations.

Table 6.4 RWH system supplier design parameters and values for Site 2

Parameter	Units	Value used by RWH system supplier
Local rainfall (annual)	mm	764
Roof area	m^2	1500
Building occupancy		300
Estimated annual demand	m^3	1350
Days required storage		6.8
Demand days		250
Filter coefficient		0.9
Runoff coefficient		0.6
Analysis period	years	25

The RWH system supplier recommended a storage tank size of 25 m^3 and estimated an annual water saving of 816 m^3 (an estimated 60% of demand met), representing annual financial savings of £1,469 (compared to the mains water supply). The three methods were applied using the same parameter values, including the annual demand figure of 1350m^3, so that this would not influence the tank sizing comparison. Method 1 simulation results suggested that the maximum achievable estimated demand met would be 46% (619 m^3). Thus the supplier's estimate of 60% was potentially over-exaggerated. To achieve this, a 9 m^3 tank would be optimum, which would yield a financial saving of £1,459 per year. Although achieving a slightly lower percentage demand met, a 9 m^3 tank would cost approximately £9,000, leading to reduced capital costs and thus a lower payback period. Leggett *et al.* (2001) highlights that tanks are often oversized mainly due to over optimistic assumptions by system designers regarding rainwater catchment and collection efficiency (as identified above). This increases cost, does not allow occasional overflow of the tank and can inhibit rainwater system uptake. Methods 2 and 3 indicated storage tank sizes of 25 and 31 m^3 respectively. As previously mentioned Method 3 should not generally be applied to larger systems; the result is included to show how it compares to the other methods. Figure 6.3 illustrates the differences in the actual (installed) and estimated tank size, highlighting the variability in tank sizes estimated and the potentially oversized installed tank.

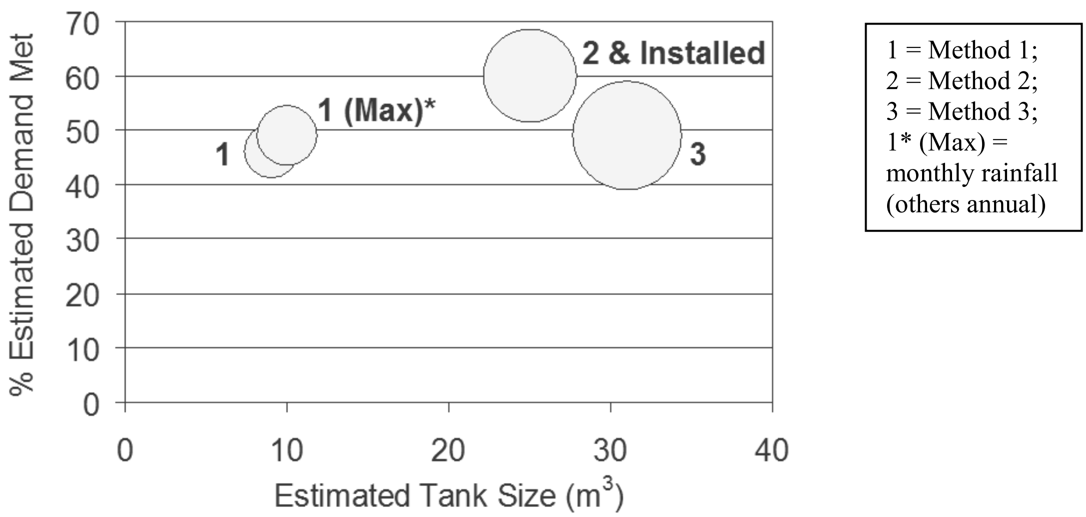


Figure 6.2 Differences in actual and estimated tank size, for Site 2

6.2.4.1 Rainfall Resolution Limitation

In order to investigate the impact of different temporal resolutions of rainfall data, a single 30-year *annual* standard average rainfall figure (the supplier used a 40-year annual non-standard average), as well as a 30-year *monthly* standard average rainfall profile, was disaggregated into average *daily* figures (month by month) within Method 1. RainCycle divides the monthly figure by the number of days within a month, thus producing *average* daily figures. In this respect, the daily data is not comparable to the variability that would be provided by using a daily long term rainfall time series (which was not available for these sites). Thus Method 1 uses *daily* values averaged from a monthly profile for the length of the simulation, which in this study was set as 25 years. The use of a 30-year average is in line with Environment Agency standard procedure.

A 'standard average' *monthly* profile is representative of the variability of a particular month and is calculated using rainfall data for each month over a 30-year period. The use of an EA standard average for an area allows internal consistency across different analyses, as the same well-known and accessible baseline is being utilised. The EA 30-year standard average (1961-1990) annual rainfall for Exeter was identified as being 807 mm (DCC, 2005), however monthly 30-year averages for Exeter were not available. In order to use monthly data, 30-year standard average monthly figures for Teignmouth (26 km from Exeter) were obtained from the Met Office (Figure 6.3). Teignmouth has a 30-year standard average annual rainfall of 820 mm and experiences the same rain shadow effect from Dartmoor as Exeter (DCC, 2005). Utilising this data is a pragmatic approach, as it is readily available to any individual, such as RWH system suppliers. Therefore the authors did not have a data advantage over those who would normally perform system designs. A synthetically generated daily long term time series could have been used, but again this would not be accessible to all.

Simulations were run using Method 1 and the annual 30-year standard averages for Exeter (Simulation 2) and Teignmouth (Simulation 3) and also the *monthly* 30-year standard average profile for Teignmouth (Simulation 4). Results of these simulations and a comparison with the first are summarised in Table 6.5. Using a 30-year standard average monthly rainfall profile rather than a non-standard annual average increased the percentage of demand met by 3%. As can be seen in Table 6.5, the potential increase in rainwater utilised also decreased the annual system cost, thereby increasing the total long-term (25 year) savings. Additionally, using the monthly profile disaggregated to daily values, rather than a single annual figure, led to a recommended tank size increase from 9 to 10 m^3.

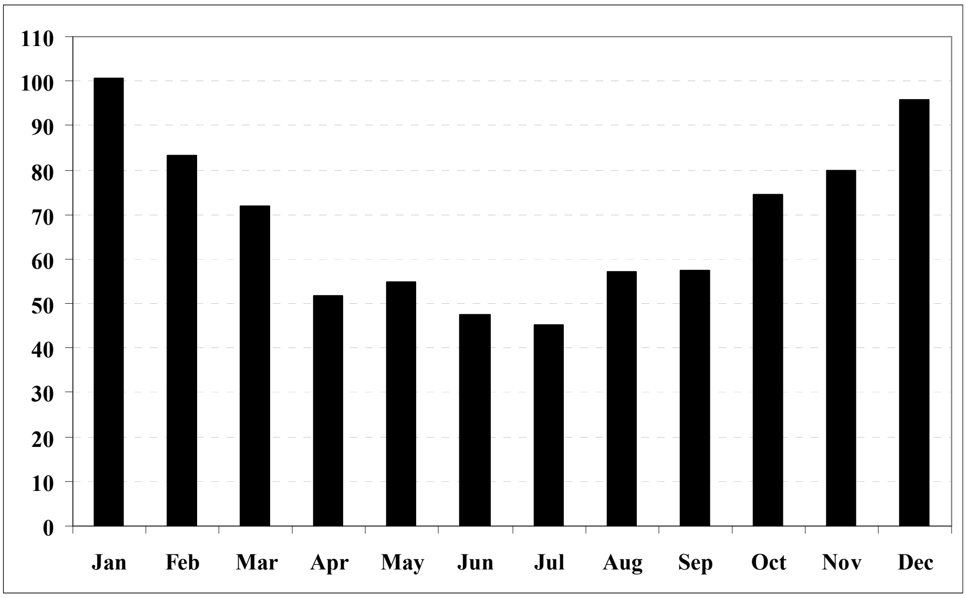


Figure 6.3 30-year standard average monthly rainfall data for Teignmouth (Met Office, 2007)

Table 6.5 Method 1 results using different rainfall data for Site 2

	Units	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Difference (1 and 4)
Demand met	%	46	48	49	49	+3
Payback period	Years	7	7	7	7	-
RWH system cost	£/year	3,087	2,970	2,935	2,935	-152
Mains supply cost	£/year	4,547	4,547	4,547	4,547	-
Savings	£/year	1,459	1,576	1,611	1,611	+152
Total savings	£/25 yrs	36,482	39,408	40,292	40,285	+3803
Recommended tank size	m^3	9	9	9	10	+1

6.2.5 Design Evaluation: Summary and Key Messages

This section has applied three RWH system design methods to two system designs. It has identified that design methods based on a simplified AR/D approach and the EA approach generated tank sizes substantially larger than the YAS-based continuous simulation. Tanks within the case studies presented are considered to be oversized for the specified demand levels and catchment sizes, which is due to the type of design method enlisted by the RWH system suppliers. However, despite overestimating tank sizes, the annual financial savings calculated by the RWH system supplier method (AR/D) were similar to those using the continuous simulation. Payback periods would be significantly longer, however, due to higher capital costs of larger tanks and thus the continuous simulation provides a better assessment of tank size in terms of cost-benefit analysis for a particular demand met level. Furthermore, it was identified that modelling several communal RWH systems as a whole rather than as separate systems has implications for tank sizing results. Additionally, for this case study site levels of demand met were limited by the catchment area size, which also had implications for financial savings. This indicates not enough consideration is necessarily given to the catchment size when designing a RWH system. Finally, it was observed that the use of non-standard average rainfall data resulted in an underestimation of the demand met and the associated savings from implementing a RWH system.

In keeping with the style of summaries of findings utilised throughout the thesis, the following key messages were determined as a result of the RWH system design evaluations:

(1) A transition from the use of simple RWH system design methods based on single calculations to more sophisticated continuous simulation tools is necessary in the UK, especially in the design of larger non-domestic systems and communal systems. This could be facilitated by increasing stakeholder (architects, the construction industry, environmental consultants) awareness of the availability and capabilities of such tools;

(2) Stakeholders considering implementing RWH within a development need to be aware of the importance of sizing the roof collection area supplying a RWH system

(as well as the building demand), *in addition* to appropriately sizing the storage tank;

(3) Stakeholders responsible for designing RWH systems should be made aware of the importance of using and promoting the use of EA standard average rainfall data, in order to promote regional consistency in analysis, whether using simple or complex design methods;

(4) Emphasis needs to be placed on the use of and increased access to higher resolution rainfall data (Mitchell (2004) recommends 5 minute intervals), especially for larger non-domestic systems, which are also likely to have a complex demand pattern. Ideally daily data but at least a monthly profile should be used (disaggregated to daily, where daily data is not available), rather than a single annual figure, which seems to be current standard practice. However, caution should be exercised in using any data based on climate change projections, as these would be subject to significant uncertainty.

The next section will explore the validity of the results derived from the application of the design methods, by comparing them with empirical data gathered through the implementation of a monitoring programme for the Innovation Centre RWH system.

6.3 RWH System Performance Evaluation

The previous section outlined the design evaluation of the Innovation Centre RWH system using modelling tools and identified that potentially 46% of the WC flushing demand (with an estimated occupancy of 300) could be met with the installed RWH. The following section utilises empirical performance data collected from water meters within the Innovation Centre, to determine if this is a realistic estimate compared with how the system actually performed. Although the system was designed for an occupancy of 300, occupancy figures from the building manager indicated that there were only 111 permanent occupants in the building during the monitoring period (Jackson, 2009). Additional non-permanent occupants, such as café customers and conference attendees, were not quantified, due to a lack of data on the former and the complexity of records for the latter.

6.3.1 Data Collection and Instrumentation

In order to monitor RWH system performance, water meters were fitted to the mains water and rainwater feeds to the header tanks within the Innovation Centre (Figure 6.4). As the two wings of the Innovation Centre are supplied by a different header tank, separate metered data was collected, allowing a deeper analysis to be undertaken. The central area (including the café and conference facility) is fed from the West wing header tank and therefore water consumption from this tank was anticipated to be significantly higher.

The meters installed were the 'MNK multi jet cold water-wet dial' style of meter (detailed specification in Appendix E) and were configured to give a pulse output to permit electronic transmission of data to a logger or centralised database. The water meters were connected to a building management system (BMS) so that data (in the form of pulse outputs) could be centralised to a database for easy manipulation and analysis. However, faults in the database were identified by the author, such as mislabelling of mains water and rainwater data series (from commissioning until October 2008), misconfiguration of the units recorded, resetting of the data series causing data to be lost or units to be changed mid-way through an event, the current dataset being erased when clicking the 'save' button and the data/database disappearing altogether in May 2009.

Figure 6.4 Innovation Centre water meters with remote monitoring wiring

The latter issue was resolved by the author spending some time deciphering the BMS and discovering that the ‘terminal’ to which the data had been saved (i.e. the server) had been changed in April 2009, but no one had been informed (hence the data simply appeared to ‘disappear’). The former issues however prevented the collection of a robust dataset as the author could not be certain that the datasets were actually what they appeared to be (i.e. was the ‘rainwater East’ dataset really ‘rainwater East’, or actually ‘mains water East’?). Despite the best efforts of the author in liaising with the building management team and the BMS installer, the BMS never functioned correctly during the monitoring period. As a contingency, throughout the same period manual meter readings were taken weekly and compared with metered records for the building obtained through the University’s Buildings and Estates Services department. However, the BMS was revisited after the monitoring duration, in October 2009, when most of the issues had been addressed. One week of data was assessed to be stable and was downloaded and analysed in detail (see Section 6.3.2.1). Only one week of data was used, so that it could be analysed in tandem with the manually collected data within the project timescale.

The system was initially commissioned in November 2007 and it was planned to monitor the system for a duration of fourteen months following completion of construction and commissioning. However, two types of issue prevented monitoring for the full duration – those of system operation and those of data integrity. The first fault was reported shortly after data collection commenced in May 2008. The author identified that a greater proportion of mains water was being used than rainwater, despite sufficient rainfall events. The author obtained the commissioning report from the RWH system manufacturer and identified that the commissioning engineer had reported that the level sensors within the header tanks were not configured correctly, therefore more mains water than rainwater was being used. The engineer had written that the issue had only been part-rectified at that time, as the header tanks were full and advised that the issue would need addressing by the building construction contractor. The author reported this to the building manager, who subsequently discovered that the issue had not been addressed post-commissioning.

Consequently, due to a conflict of interest and warrantee coverage between the system and building implementation parties (i.e. no party wanted to claim ownership of the issue) the level sensors were not rectified until September 2008. Thus the system had been using mains water unnecessarily for nine months. After this was rectified, during October 2008, the gutters, underground storage tank and filters were cleaned to ensure the system was performing optimally. Consequently there was a low water level in the tank during October and November 2008 whilst it refilled. Therefore the RWH system was only performing as intended for eight months of the monitoring period. As a result only data post-remedial works (December 2008 to July 2009) is used within the analyses in the sections that follow.

In addition to the issue outlined above, there were two periods, one during February 2009 and the second during April 2009, when system faults occurred. The first was due to a faulty sensor that showed harvested rainwater was being pumped to the West core header tank, but that no harvested rainwater was being consumed within the West core. The second was caused by a seized backwash valve that caused the 'check filter' light to come on. This triggered the system to use the mains top-up continuously and hence harvested rainwater consumption fell. At the beginning of May the system was reconfigured and the faulty valve replaced with a reconditioned one, under the maintenance contract and consequentially harvested rainwater consumption increased.
During the monitoring period it was primarily system malfunction and delays in resolving the issues that caused the mains top-up to be used for prolonged periods, rather than a deficit of rainfall-runoff/storage capacity. A chronology of the issues experienced is summarised in Table 6.6.

Table 6.6 Innovation Centre RWH system fault log chronology

Date fault reported	Fault/Issue	Date of resolution	Duration (mths)
30/11/07	Level sensors configured incorrectly	09/09/08	9
19/05/08	Rainwater and mains data series incorrectly labelled on the BMS*	21/10/08	5
24/02/09	Faulty sensor in West core	12/05/09	3
31/03/09	Seized backwash filter	12/05/09	1.5
09/06/09	BMS* data 'disappeared'	02/02/10	7

*BMS = building management system

As Table 6.6 illustrates, there were lengthy delays (durations between 1.5 and 9 months) in resolving the reported faults. The most ‘speedy’ of resolutions (1.5 months) only occurred so near to the fault reported date as a maintenance visit was already fortuitously scheduled within 6 weeks of when the fault occurred. It could not be resolved any faster as the maintenance provider grouped their visits according to area and any extra journeys would incur additional costs. This highlights that some repair work can be delayed due to externalities, such as business interests. Overall, the delays were due to a number of reasons:

- Conflicts of responsibility caused by the number of implementing parties;

- A lack of ownership even when the party responsible for rectifying the problem was identified due to questions over warrantee coverage;

- Negotiation of a part-maintenance contract with the system supplier, to maintain validity of the warrantee, but reduce costs by covering some maintenance activities in-house;

- Maintenance contract negotiation impacting designation of ownership of the fault;

- The in-house maintenance team having a lack of experience with RWH systems.

These incidents illustrate that even where a warrantee and maintenance agreement are put in place, RWH system implementation requires a significant amount of attention to detail. They also require the appropriate experience to identify and resolve faults within timescales that do not affect the system’s ability to operate effectively. Additionally, they require, from the start of implementation, the designation of *one single party* who is responsible for *any* issues that arise with *any part* or *associated* part of the system. Such a recommendation is made in Shaffer *et al.*’s (2004) *‘Model Agreement for Rainwater and greywater Use Systems’*.

Alternatively, if there have to be multiple interested parties, detailed boundaries of obligation need to be delineated and contractual arrangements made, from the outset of installation. This would not only reduce confusion with regard to fault responsibility, but could also impose a penalty for not achieving the required (agreed) level of service.

This could be set as completing a fault resolution within a timescale reasonable for the issue to be resolved. For example, two weeks to replace a faulty valve. A copy of the outline agreement contained within this document was given to the building manager, but as far as the author knows was not actioned. A recommendation from this aspect of the monitoring study would be that a document 'signposting' all relevant and useful documents pertaining to the implementation of RWH systems should be compiled and made available to RWH system suppliers and their clients.

With regard to energy consumption, the RWH system did not have an integrated energy monitor for the pump included in the system. The author contacted the supplier to ascertain whether one could be fitted and was told this was not possible, although they were looking into it for inclusion on future systems. The building construction company was contacted to ascertain if such a device could be fitted to the system independently, but was told it would not be possible under their contractual agreement. Therefore a proxy measure of energy use was utilised. This consisted of calculating the number of pump starts from the volume of water that had been consumed during the monitoring period. This is discussed in full in Section 6.3.5.

6.3.2 Data Analysis

Despite the issues and faults outlined in the preceding section, eight months of weekly performance data was collected and analysed. Runoff could not be directly measured as part of the monitoring activities, due to the complexity of the roof drainage (i.e. the runoff did not converge to one central above-ground point on which a meter could be installed) and therefore was calculated by multiplying the rainfall time series for the Whipton weather station (described in Chapter 5, Section 5.2.3) by the catchment area. Further to this, a data series entitled 'cumulative runoff (with coefficient)' was generated by multiplying the runoff data series by the runoff coefficient (C), which was calculated using the following equation (Fewkes, 2004):

$$C = Q / RA \qquad \textbf{Equation 6.6}$$

Where Q = rainfall runoff (l), R = rainfall (mm) and A = catchment area (m^2).

Using this coefficient yielded a more realistic estimate of the runoff available. The monthly runoff coefficient range calculated for the Innovation Centre system was 0.91 to 1.0, with the average being 0.97. Therefore the 0.6 used by the system supplier in the design (Section 6.2.4) was arguably conservative. The depression storage loss (E (l)) was also calculated by rearranging the following equation:

$$Q = (RAC) - E$$ **Equation 6.7**

To form:

$$E = (RAC) - Q$$ **Equation 6.8**

Depression storage loss in mm was then calculated by dividing the result by the catchment area of 1500 m^2. For the Innovation Centre, E ranged between 0 and 0.04 mm, with the average being 0.01. This is low in comparison to previous studies, such as Fewkes (2004) where E was in the region of 0.2 mm. This difference could be attributable to geographical differences (Fewkes' study was conducted in Nottinghamshire) and variation in roof type. The primary catchment surface in the present study was constructed of smooth aluminium, whereas in the previous study it consisted of granular-faced concrete tiles. Regression analysis was undertaken to determine the relationship between the two parameters, which is illustrated in Figure 6.5. As would be expected the relationship is linear, with the runoff coefficient increasing as depression storage loss decreases.

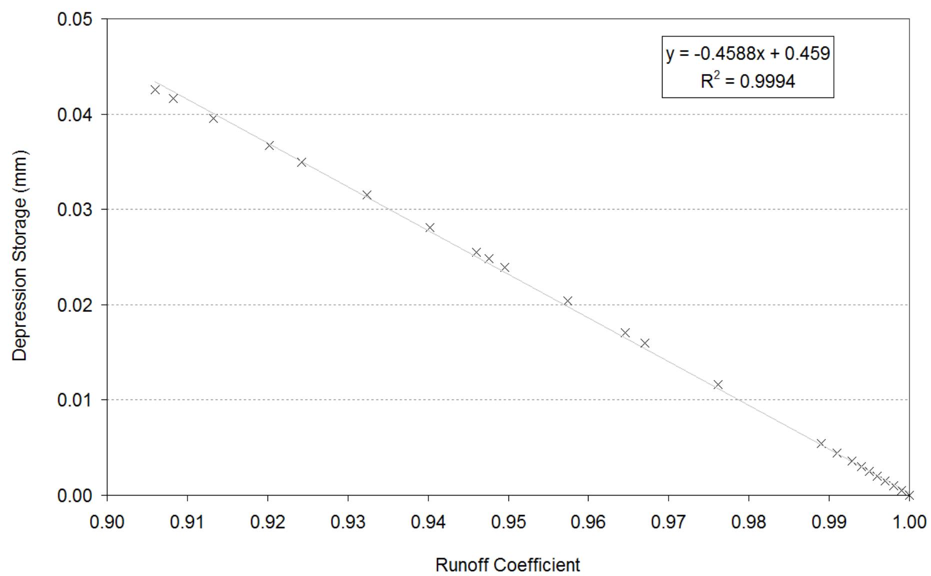


Figure 6.5 Regression analysis for depression storage and runoff coefficient

It was also not possible to measure the overflow from the underground tank as this too was below-ground and installation of a meter was not possible when the system was installed. Therefore to identify potential tank overflow events the capacity of the tank (25 m^3) was subtracted from runoff values and the volume of harvested rainwater used over the corresponding duration was also subtracted (as this volume was put into supply it effectively represents additional tank capacity). The total number of potential tank overflow events calculated on this basis was 9 and these are summarised in Table 6.7.

Table 6.7 Potential overflow events from the Innovation Centre RWH system

Week	Runoff (m^3)	Harvested Rainwater Consumed (m^3)	Potential Overflow (m^3)
20/01/09	47.27	7.83	14.44
27/01/09	52.54	7.10	20.44
03/02/09	37.24	7.42	4.82
10/02/09	63.87	7.26	31.61
10/03/09	35.89	8.87	2.02
09/06/09	59.45	8.19	26.26
07/07/09	42.17	7.87	9.30
28/07/09	55.07	7.11	22.96
04/08/09	62.53	7.44	30.09

The weekly WC mains water and rainwater consumption values are summarised in Figure 6.6. Cumulative calculated runoff, potential overflow, total WC demand, rainwater and mains water top-up consumed for the Innovation Centre are summarised in Figure 6.7 (a full table of values is located in Appendix E). It is clear that throughout the winter the system consistently provided enough harvested rainwater to fulfil the full WC demand. The dip in WC demand due to the Christmas holiday period is clearly evident in Figure 6.6. Additionally, a fault that occurred with the system during April (described in Section 6.3.1) is also clearly identifiable, where mains water top-up exceeds rainwater consumed. Thus, the fault was responsible for the significant drop in harvested rainwater consumed in April and subsequent recovery. The peak in May was most likely due to a large conference being held. Figure 6.8 shows the difference in harvested rainwater and mains water top-up consumed by each wing of the building. As hypothesised, due to the presence of the café and conference facility in the West core (as well as a higher proportion of the building's permanent occupants) the volume of water consumed in this wing is higher than for the East.

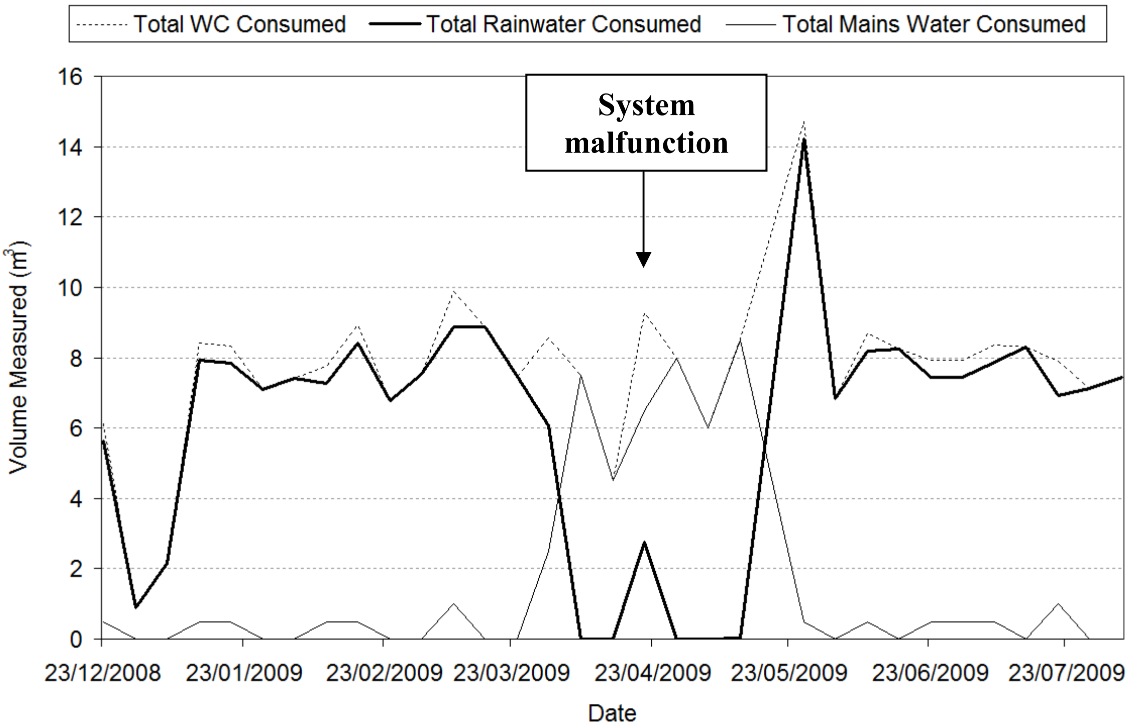


Figure 6.6 Total weekly WC mains water and rainwater consumed volumes for the Innovation Centre

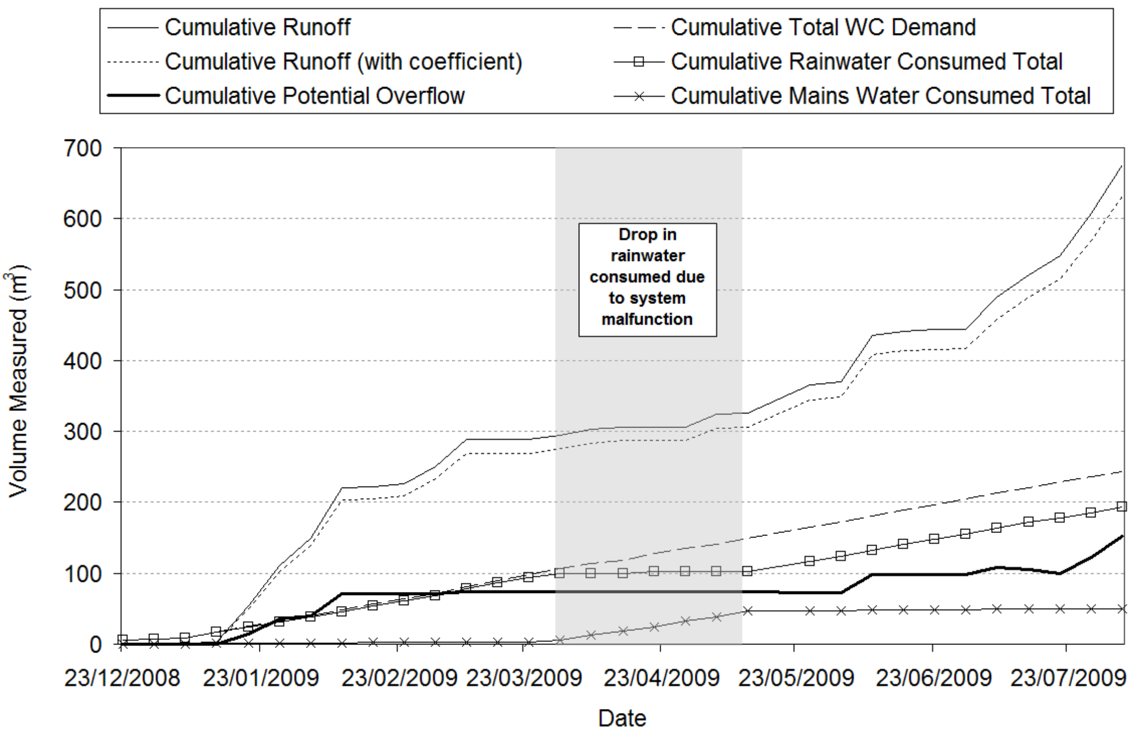


Figure 6.7 Cumulative runoff, overflow, total WC demand, rainwater and mains water top-up consumed for the Innovation Centre

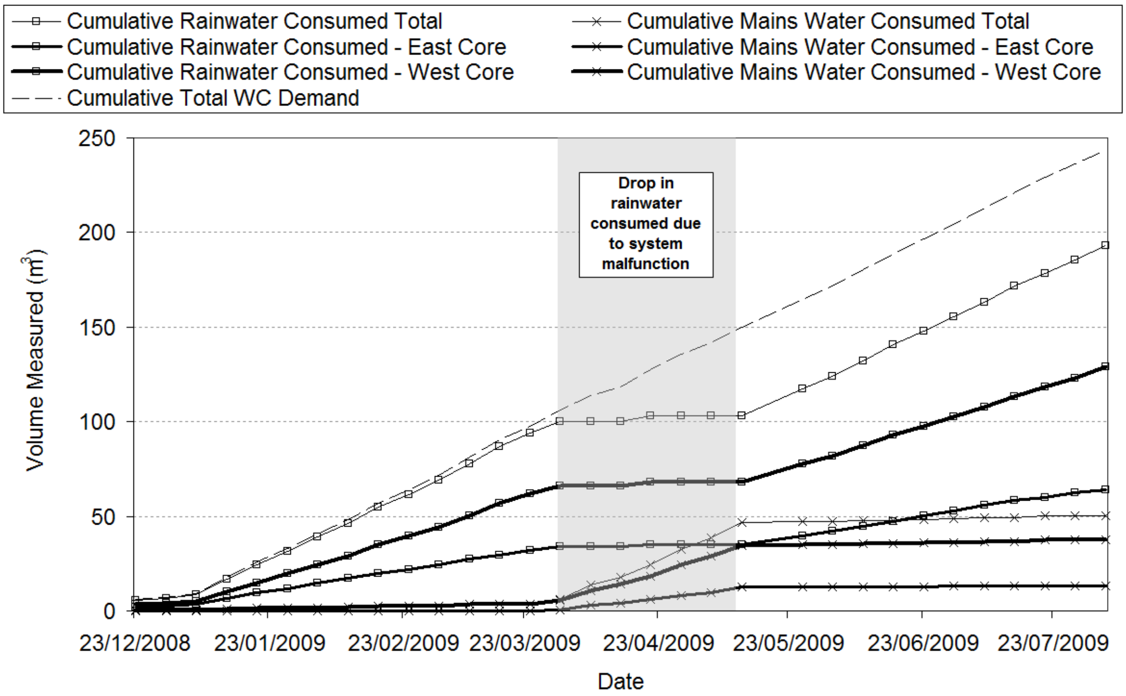


Figure 6.8 Cumulative total WC demand, rainwater and mains water top-up consumed for the Innovation Centre West and East wings

The total volumes of harvested rainwater and mains water top-up consumed during the eight month monitoring period were 193.07 m^3 and 50.50 m^3, respectively. Thus RWH provided approximately 79% of the total WC demand. In order to further quantify these figures in terms of actual water savings, a full analysis of water saving efficiency is undertaken in Section 6.3.3. For the January to June period the total volume of harvested rainwater consumed was 148.93 m^3. Therefore the potential annual volume of harvested rainwater consumed is 297.86 m^3.

The total WC demand during the eight month monitoring period was 243.57 m^3. This is equivalent to 40,595 6L flushes, 81,190 3L flushes or 27,063 6 and 3L flushes at a ratio of 2:1. This ratio was established by analysing flush counter data (Section 6.4.7). Dividing the total WC demand across the 163 monitoring days (weekends were not included as the building was assumed to be predominantly empty) is equivalent to an average daily WC demand of 1.49 m^3 and average daily flush frequencies of 249 6L flushes, 498 3L flushes or 100 6 and 3L flushes at a ratio of 2:1.

6.3.2.1 Innovation Centre BMS Data

As previously discussed, the BMS did not function correctly during the monitoring duration. However, it was revisited in October 2009, when most of the issues had been rectified. Data at intervals of 30 minutes was downloaded for one week from 19 to 23rd October (Monday to Friday), in order to examine its robustness. One week was used, as it provided a manageable dataset to examine in the last stages of the project. The data is summarised in Figure 6.9. A larger proportion of harvested rainwater was being used than mains water top-up during the week and the daily profiles of consumption were similar for the five days.

In total 8.59 m^3 of harvested rainwater was consumed, in comparison with 5.23 m^3 of mains water top-up. Thus the RWH system provided 62% of the total WC demand during this period. The total WC demand during this period was 13.83 m^3, resulting in an average daily demand of 2.77 m^3. This is somewhat higher than the 1.49 m^3 derived from the manual monitoring period, but could be attributable to a number of reasons. For example, there may have been a greater number of occupants in the building during October 2009 due to it being the first month of the University term, or the conference facility may have been in use. The total daily WC demand was equivalent to 461 6L flushes, 922 3L flushes or 184 6 and 3L flushes at a ratio of 2:1.

The BMS data permitted further analysis of WC consumption at a sub-daily resolution, something that was not possible with the manual weekly readings in the previous section. Consequentially, the total WC demand figures are compared to data collected from the flush counter monitoring programme, described in Section 6.4.7, to identify whether patterns from the two datasets corroborate.

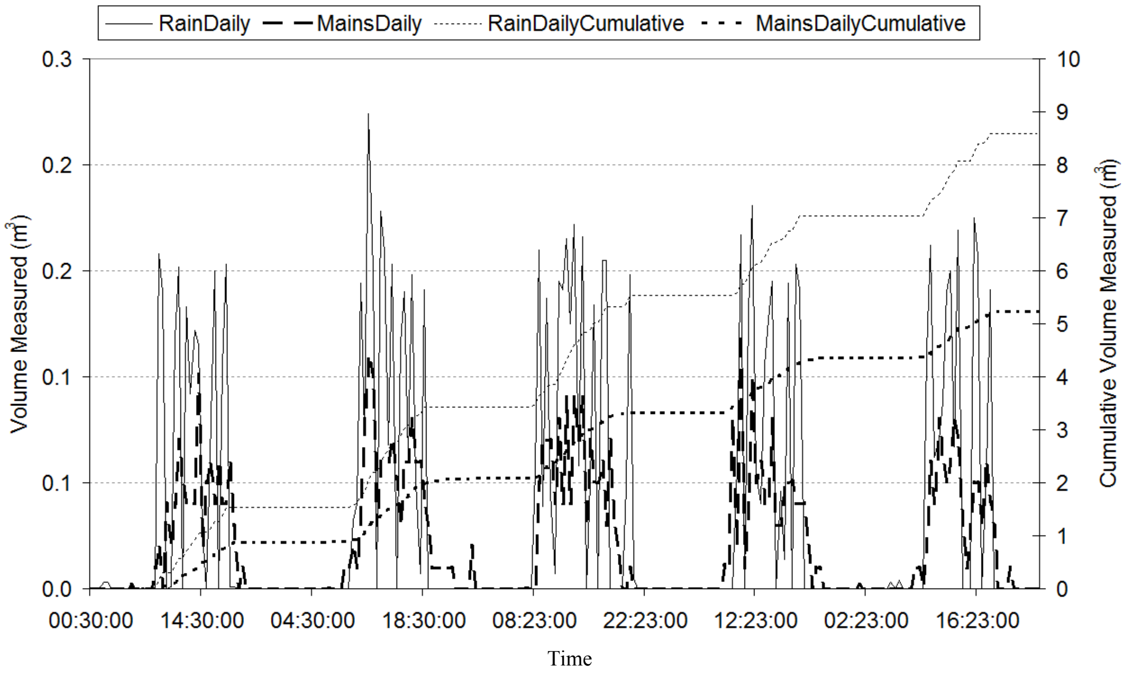


Figure 6.9 Daily and cumulative harvested rainwater and mains water consumption data from the Innovation Centre BMS (19-23rd October 2009)

6.3.3 Innovation Centre Water Saving Efficiency

The calculation of water saving efficiency (E_T) is a method of determining the performance of a RWH system (Dixon *et al.,* 1999). It is a percentage measure of mains water conserved in relation to total demand and is calculated by dividing the volume of rainwater consumed within a WC by the total demand of the WC. It is summarised in Equation 6.9.

$$E_T = 100.V / D \qquad \textbf{Equation 6.9}$$

Where D = total WC demand (m^3) and other terms are as previously defined.

The E_T of the Innovation Centre RWH system was calculated using the data from the previous section and is summarised in Figure 6.10, alongside the modelled and estimated profiles from Section 6.2.4. The system regularly provided 100% of the total WC demand of the building with an occupancy of 111 and the lowest E_T was 87% (not including readings during the period when the system was malfunctioning due to a faulty valve). The average E_T was 97% for the period monitored. For the West core the range was 83-100% and for the East core was 84% (though this only occurred once, the rest of the time it was at 100%).

However, extrapolating the monitored data to an occupancy of 300 (the design occupancy) reveals that the E_T drops to an average of 35% (below the system supplier estimate of 60%). This confirms the assertion outlined in Section 6.2.4 that manufacturer/supplier water saving efficiency estimates are potentially over-optimistic. It also reaffirms the importance of using representative demand estimates in RWH system tank sizing assessments. However, it should be noted that due to operational issues data was only collected for the winter and spring period thus the E_T during the summer may have been lower, due to decreased rainfall events and therefore the average E_T across a full year may have been lower than the range outlined above.

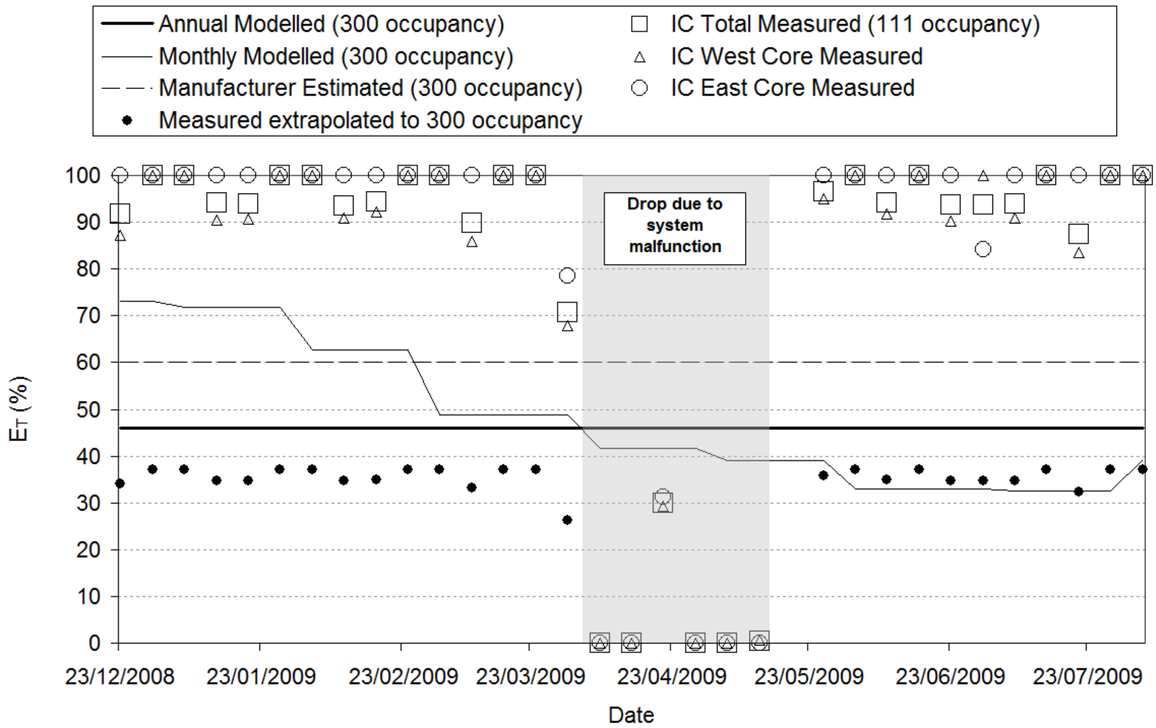


Figure 6.10 Water Saving Efficiency (E_T) of the Innovation Centre RWH System compared with modelled values

6.3.4 Innovation Centre Cost Savings

In terms of cost savings associated with the E_T of the system, direct (water supply) and indirect (sewerage) savings are summarised in Table 6.8 for the monitoring period. Mains water supply and sewerage unit costs were provided by the building management team (Dyer, 2010). These were:

- Mains water supply - January 2009 to April 2009 = 157.00p/m^3; April to October 2009 = 169.11p/m^3;
- Sewerage – January 2009 to April 2009 = 242.16p/m^3; April to October 2009 = 257.79p/m^3.

The system provided a direct saving of £313.93 from the end of December 2008 to the beginning of August 2009 period. It should be noted that this is not a full yearly profile and the savings achieved during the summer period would possibly be lower. Nonetheless, this data was used to calculate a January to June saving (£241.49), which was extrapolated to a potential annual saving of £482.98. This figure does not include the saving that would have been made if the RWH system had not developed a fault during April 2009. In order to incorporate this saving, the average weekly saving was calculated from the full data set (£10.98) and in-filled for the April weeks. This resulted in a corrected potential annual saving of £592.68.

Arguably, the uncorrected annual saving figure may be more realistic, as it potentially represents periods when increased mains water top-up would be required, such as the summer months. However, building occupancy may drop during this period due to employees taking time off during the school holidays and therefore there may also be a corresponding drop in WC demand. This could potentially balance the reduced rainfall availability during these months. The uncorrected figure also represents a profile in which problems with system function were experienced, which, based on this and previous studies (section 2.3.7) is unfortunately a likely occurrence.

Indirect cost savings were also calculated which represent the cost savings gained by a reduced volume of mains water being used to calculate sewerage charges. For the monitoring duration the system achieved an indirect saving of £457.56 due to mains water being replaced by harvested rainwater and therefore being exempt from the sewerage disposal charge calculation. Normalising this for the April system fault and extrapolating the January to June saving to an annual figure (as was done for direct savings) results in a potential corrected indirect annual saving of £874.01 (uncorrected = £704.76). Combining the direct and indirect cost savings for the actual data and the uncorrected and corrected annual profiles results in total cost savings of:

- Total cost savings (Dec’08-Aug’09) – £771.49;

- Annual total cost savings (uncorrected) – £1187.74;
- Annual total cost savings (corrected) – £1466.69.

In Section 6.2.4 it was identified that the RWH system supplier estimated an annual water saving of 816 m^3 and an annual saving of £1,469 for the Innovation Centre, supplying 300 occupants (it is unknown whether the supplier used both water supply and sewerage disposal unit costs). Optimising the underground storage tank size using the continuous simulation resulted in an estimated maximum annual water saving of 619 m^3 (46%) with a 9 m^3 tank, which would yield a financial saving of £1,459 per year (this included both savings from mains water saved (£1.11/m^3) and a reduced sewerage charge (£2.25/m^3)). Comparing these figures reveals that they are remarkably similar, despite being based on different system configurations and demand levels.

The difference becomes noticeable when calculating payback periods. Whole life cost payback periods cannot be calculated, as the full maintenance costs of the system over its operational life have yet to be determined (as the system is new). However, capital cost payback periods can be derived, using capital cost figures of £15,500 (for the actual Innovation Centre 25 m^3 system) and £9,000 (for the hypothetically more efficient 9 m^3 system) and the annual savings calculated from the performance monitoring data. The resultant capital payback periods are 11 and 6 years, respectively. It is clear that although the system supplier's annual savings calculation yielded a similar result to that derived from monitoring data, the payback period of the system could have been reduced by using a smaller system, as the system is oversized for the current number of building occupants.

Additionally, incorporating the annual maintenance contract cost of £1,489.25 for a 25m^3 system across the 25 year operational life would increase the payback period substantially. This indicates the need for greater innovation in the design and configuration of RWH systems to reduce maintenance requirements. Encouragement should be provided to facilitate the design of systems that only require the type of maintenance that can be undertaken fully by a system/building owner, rather than a dedicated company at additional expense.

Table 6.8 Weekly cost savings associated with mains water supplemented by harvested rainwater for the Innovation Centre

Week	Total Mains Water Consumed (m^3)	Total Harvested Rainwater Consumed (m^3)	Mains Water Cost (£)	Rainwater Saving (£)	Sewerage Saving (£)
23/12/2008	0.50	5.62	0.79	8.82	12.92
30/12/2008	0.00	0.88	0.00	1.38	2.02
06/01/2009	0.00	2.16	0.00	3.39	4.97
13/01/2009	0.50	7.93	0.79	12.45	18.23
20/01/2009	0.50	7.83	0.79	12.29	18.00
27/01/2009	0.00	7.10	0.00	11.15	16.32
03/02/2009	0.00	7.42	0.00	11.65	17.06
10/02/2009	0.50	7.26	0.79	11.41	16.70
17/02/2009	0.50	8.43	0.79	13.23	19.37
24/02/2009	0.00	6.78	0.00	10.64	15.59
03/03/2009	0.00	7.54	0.00	11.84	17.33
10/03/2009	1.00	8.87	1.57	13.93	20.39
17/03/2009	0.00	8.89	0.00	13.96	20.44
24/03/2009	0.00	7.48	0.00	11.74	17.20
31/03/2009	2.50	6.06	3.93	9.51	13.93
07/04/2009	7.50	0.00	11.78	0.00	0.00
14/04/2009	4.50	0.00	7.07	0.00	0.00
21/04/2009	6.50	2.77	10.21	4.35	6.37
28/04/2009	8.00	0.00	12.56	0.00	0.00
05/05/2009	6.00	0.00	10.14	0.00	0.00
12/05/2009	8.50	0.03	14.37	0.05	0.07
26/05/2009	0.50	14.22	0.85	24.03	34.85
02/06/2009	0.00	6.84	0.00	11.56	16.76
09/06/2009	0.50	8.19	0.85	13.84	20.07
16/06/2009	0.00	8.25	0.00	13.94	20.22
23/06/2009	0.50	7.44	0.85	12.57	18.24
30/06/2009	0.50	7.44	0.85	12.57	18.24
07/07/2009	0.50	7.87	0.85	13.30	19.29
14/07/2009	0.00	8.31	0.00	14.04	20.37
21/07/2009	1.00	6.91	1.69	11.68	16.94
28/07/2009	0.00	7.11	0.00	12.02	17.43
04/08/2009	0.00	7.44	0.00	12.57	18.24
Total	**50.50**	**193.07**	**81.45**	**313.93**	**457.56**

6.3.5 Quantifying Energy Consumption by Proxy

Previous studies (Dixon, 2000; Roebuck, 2008) have utilised simple equations, such as Equation 6.10 and Equation 6.11 to calculate RWH system pump energy consumption (E) in order to calculate system operating costs.

$$E(kWh) = P_R . O_D \qquad \textbf{Equation 6.10}$$

Where P_R = pump rating (kW) and O_D = operating duration (h) and O_D is:

$$O_D = V / P_C \qquad \textbf{Equation 6.11}$$

Where V is volume of rainwater pumped i.e. consumed (m^3) and P_C is the pump capacity (m^3/h). P_R and P_C can be obtained from pump specification documents. V can be estimated by calculating a demand value or derived from empirical data, where monitoring equipment is in place.

However, these studies did not quantify CO_2 emissions. Additionally, they did not consider the efficiency of the pump, or incorporate parameters to distinguish between pump start-up and pump operating energy consumption. In calculating the total energy consumption, the differential energy consumption of these phases needs to be considered, as around 60% more energy can be consumed on start-up (Yago, 2008). For example, a pump may consume 0.020 kWh for the first 60 seconds of operation and then revert to 0.012 kWh for the rest of the operating duration. This has the potential to be substantially higher, depending on the type of pump utilised and the pressure at which the pump is set to start (if float switch levels are not used). One study found the transient pump start-up peak power was up to four times that of the running power demand for a household system, due to the system pressure frequently dropping below 350 k Pa (Gardner *et al.*, 2008).

In light of this an improved method was developed, adapted from Equations 6.10 and 6.11, to incorporate parameters for pump efficiency and start-up/operating energy. These are calculated with the use of other parameter values that are readily available from pump or RWH system manuals. These include header tank capacity and float switch on/off levels. The improved method also includes the estimation of CO_2 emissions.

6.3.5.1 *An Improved Energy-Carbon Calculation Method*

To accommodate the additions outlined previously, E becomes E_2 and the improved method is defined as:

$$E_2 = E_{PST} + E_{POT}$$ **Equation 6.12**

Where E_{PST} is the total energy consumed on pump start-up (kWh) and E_{POT} (kWh) is the total energy consumed during operation. Thus:

$$E_{PST} = E_{PS} + (E_{PS}.S_F)$$ **Equation 6.13**

Where

$$E_{PS} = P_R.O_{DS}$$ **Equation 6.14**

S_F is the start-up energy factor (% extra energy used on start-up) and O_{DS} is the start-up operating duration (h).

And:

$$E_{POT} = P_R.O_{DO}$$ **Equation 6.15**

Where O_{DO} is the operating duration:

$$O_{DO} = V_1 / P_C$$ **Equation 6.16**

Where:

$$V_1 = V.O_V$$ **Equation 6.17**

O_V is the percentage of volume consumed pumped during operation (1- S_V), obtained from the pump manufacturer.

And:

$$O_{DS} = V_2 / P_C$$ **Equation 6.18**

Where:

$$V_2 = V.P_S.S_V$$ **Equation 6.19**

S_V is the percentage of volume consumed pumped on start-up and

$$P_S = \frac{V}{((H_C.T_2)-(H_C.T_1))}$$ **Equation 6.20**

Where P_S is the number of pump start-ups
H_C = header tank capacity (m^3)
T_1 = float switch on level (%)
T_2 = float switch off level (%).

These can be obtained from RWH system manuals or specifications.

A pump is never 100% efficient and therefore the pump efficiency (P_E) must be included to calculate total energy consumption (E_{TOT}). P_E is defined as:

$$P_E = P_R / P_I$$ **Equation 6.21**

Where P_I = pump input power (kW), which can also be obtained from specifications.

Thus the final equation for calculating RWH system pump total energy consumption (E_{TOT}) is:

$$E_{TOT} = E_2 + (E_2.(1-P_E))$$ **Equation 6.22**

Consequently the carbon dioxide emission (E_{CO2}) can be calculated from:

$$E_{CO2}(kg) = E_{TOT}.E_C$$ **Equation 6.23**

Where E_C is the CO_2 emitted from electricity derived from the combustion of coal, that being 1.043 kg/kWh (CDIAC, 2010). Other CO_2 equivalent values for this factor could be used, depending on the electricity source or the unit of comparison. Again, it should be noted that these are operational energy and carbon values, not embedded.

Comparison of operational energy values for decentralised RWH and the centralised WDS from a range of studies are discussed in Section 6.3.5.6.

6.3.5.2 Application of the Improved Method

In order to test the devised method, it was applied to the Innovation Centre data described in the previous sections.

6.3.5.3 Innovation Centre RWH System Pump Data

The Innovation Centre building RWH system has a stainless steel submersible 1.1kW pump situated in the underground storage tank. As there is no ultra-violet (UV) disinfection fitted to the system the primary source of energy consumption is this pump unit. System specification information required for parameterisation within the application of the improved method was gathered and is summarised in Table 6.9.

Table 6.9 Parameters and their values used to calculate energy consumption and CO_2 emissions of the Innovation Centre RWH system

Parameter	Unit	Value	Parameter	Unit	Value
P_R (pump rating)^	kW	1.1	T_2 (float switch off level)^	%	95 (0.95)
P_I (pump input power)^	kW	1.62	S_F (start-up factor)^L	%	0.6
P_C (pump capacity) ^{L}	m^3/h	3.39	S_V (start-up volume)*	m^3	0.001 (0.1% of 1 m^3)
H_C (header capacity)^	m^3	0.8	O_V (operating volume)*	m^3	0.9999 (1-S_V)
T_1 (float switch on level)^	%	75 (0.75)	P_E#	%	68 (0.68)

^ From system specification ^{L} From literature * Estimated # Calculated

The pump capacity (P_C) was derived using the pump rating (P_R) in conjunction with data taken from Roebuck (2008). These values are summarised in Table 6.10. The other requirement of the improved method is the availability of information on the volume of rainwater pumped (i.e. supplied/consumed). Although this can be estimated, a more accurate energy/emission calculation is facilitated by utilising empirical data. As described in the previous section of this chapter, such data was collected from the Innovation Centre and this data was used to calculate total pump energy/emissions.

Table 6.10 Pump rating and capacities for a rainwater harvesting system pump (modified from Roebuck, 2008)

Height of building (m)	10	20	30
Power rating (kW)	**Capacity (m^3/h)**		
0.8	3.60	3.00	1.80
1.0	3.78	3.30	2.70
1.1	3.84	**3.39**	2.91
1.2	3.90	3.48	3.12
1.4	4.02	3.60	3.30

6.3.5.4 Innovation Centre RWH System Volume Pumped Data

The monthly rainwater volumes consumed within the Innovation Centre RWH system are summarised in Table 6.11. As previously mentioned, due to system operating issues, only eight complete months of useable data was available. Six months of this data is used within the proceeding energy/emission calculation to yield estimates for a half-year profile.

Table 6.11 Monthly rainwater volumes supplied by the Innovation Centre RWH system

Month	**Volume (m^3)**	**Month**	**Volume (m^3)**
January	25.02	April	2.77
February	29.89	May	14.25
March	38.84	June	38.16
Total	**148.93**		

6.3.5.5 Improved Method and Simplified Method Comparison

A simple spreadsheet tool (Figure 6.11) was developed using the equations outlined in Section 6.3.5.1, to calculate the energy consumption and operational CO_2 emissions associated with the rainwater used within the Innovation Centre building (the macro within the tool and values calculated for intermediate parameters are located in Appendix E). Additionally, values were calculated using the simplified method to allow a comparison. These results are summarised in Table 6.12. As can be seen, the improved method increases the estimated pump total energy consumption from 0.32 kWh/m^3 to 0.54 kWh/m^3 and CO_2 emissions from 0.34 kgCO_2e/m^3 to 0.56 kgCO_2e/m^3.

This indicates that compared with the improved method, the simplified method underestimates total pump energy consumption and carbon emissions by 60%. This highlights the significance of the contribution of pump start-up energy consumption and pump efficiency and the importance of their inclusion in calculating pump total energy consumption and CO_2 emissions. The figure estimated in the present study also compares well to that identified by Gardner *et al.* (2008), which was 0.54 kWh/m^3 (from a domestic property).

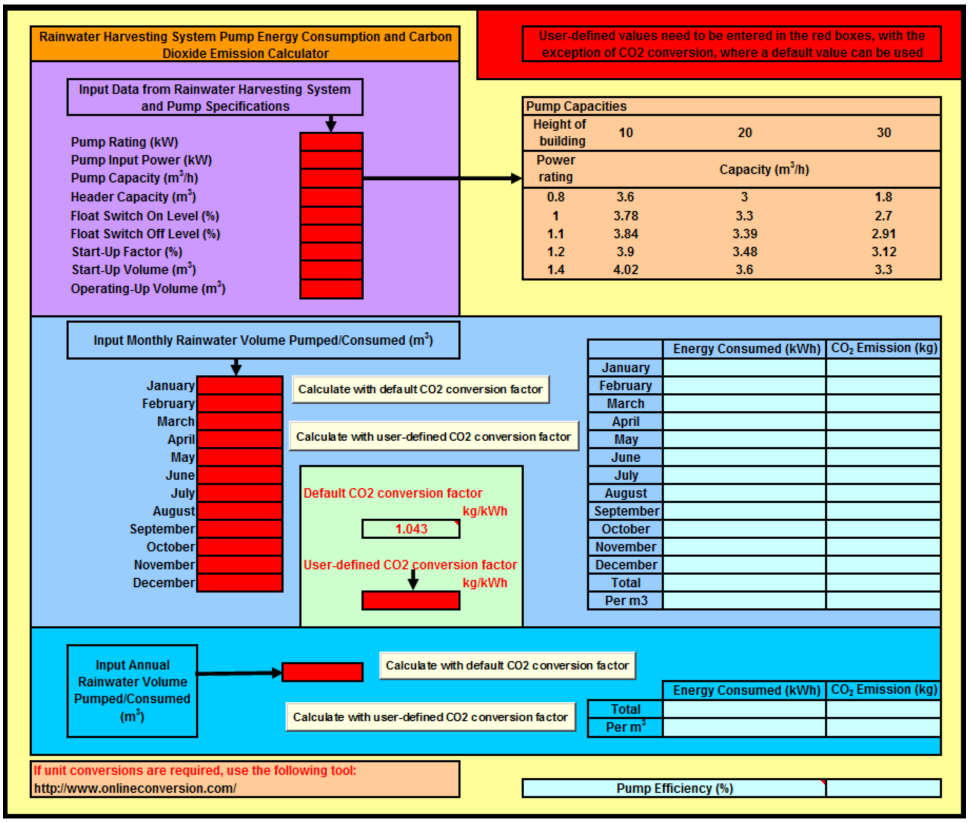


Figure 6.11 Graphical User Interface of the RWH System Pump Energy and Carbon Tool

Table 6.12 Results of the Improved Method Compared with the Simplified Method

Month	**V (m^3)**	**E (kWh)^{SM}**	**E_{CO2} (kg)^{SM}**	**E_{TOT} (kWh)^{IM}**	**E_{CO2} (kg)^{IM}**
Jan	25.02	8.12	8	13.40	13.97
Feb	29.89	9.70	10	16.00	16.69
Mar	38.84	12.60	13	20.80	21.69
Apr	2.77	0.90	1	1.48	1.55
May	14.25	4.62	5	7.63	7.96
Jun	38.16	12.38	13	20.43	21.31
Total	148.93	48.33	5	79.75	83.17
Per m^3	**1**	**0.32**	**0.34**	**0.54**	**0.56**

SM = Simplified Method **IM = Improved Method**

The first quarterly electricity bill (January to April 2009) for the Innovation Centre was obtained from the building management team (Dyer, 2010). This enabled the per unit (kWh) electricity cost to be identified (10.42p) and subsequently the cost of the pumping energy was quantified and is summarised in Table 6.13.

Table 6.13 Cost of electricity associated with RWH pumping for the Innovation Centre

Month	E_{TOT} (kWh)	Cost (£)	Month	E_{TOT} (kWh)	Cost (£)
Jan	13.40	1.39	Apr	1.48	0.15
Feb	16.00	1.66	May	7.63	0.79
Mar	20.80	2.16	Jun	20.43	2.13
Total	**79.75**	**8.29**	**Per m^3**	**0.54**	**0.06**

The quarterly total electricity consumption was 71513 kWh (January to April), resulting in the proportion attributable to the RWH pump being 0.072%. This is perhaps not surprising given the quantity of electrical equipment (lights, PCs, servers etc) present in most offices, but it does highlight that the energy consumption of the RWH system is marginal compared with the office's overall consumption.

6.3.5.6 Comparison with other studies

To place the results of the calculations in the previous section in context, the per unit (kWh/m^3) energy consumption value was plotted against normalised values from previous studies, summarised in Table E-1, Appendix E. This included comparative values for WDSs. As can be seen from Figure 6.12 the variability of energy consumption attributed to both types of system is high, due to the different locations and operating conditions from which the values originate. The unit value for the current study is towards the lower end of the scale. The values at the higher end of the scale are from slightly older studies (in particular the 7.1 kWh/m^3 (Brewer *et al.*, 2001)). Therefore the difference could be attributable to an improvement in pump efficiency or improved implementation reducing the number of pump start-ups required. As previously mentioned, this phase of pump operation consumes proportionally more energy. Values for CO_2 emissions are not plotted in a similar way as the normalisation process involves the use of too many assumptions and therefore it would not be appropriate to interrogate the data in the same way.

The proportion of the Innovation Centre building's energy consumption attributable to the RWH system was 0.072%. Previous research by Gardner *et al.* (2008) conducted on a development of 22 households in Australia revealed that the proportion of total energy attributable to the RWH was between 7 and 12% (Figure 6.13). The Innovation Centre data has identified that this is substantially less for an office-based system, though there are of course differences between the two case studies, such as a significant amount of electrical equipment in the Innovation Centre, which will form a higher proportion of overall energy consumption. In Gardner's study the proportion was similar to that of the air conditioning system in some households and less that the hot water system. The prevalence of domestic air conditioning systems in the UK is far less than in Australia and therefore does not provide a suitable comparator.

Previous UK research (EA, 2008a) calculated that the CO_2 emission of heating 1m^3 to 28°C with gas for showering was 6.7 kg. Taking the average shower as using 7L/min and the average shower duration to be 12 minutes (Waterwise, 2009), this equates to 12 showers in 1m^3 and 0.56 kg CO_2 per shower. This is comparable to the unit RWH pumping value calculated in this study (0.56 kgCO_2/m^3). Thus in terms of emission trade-offs, one less shower potentially permits 1m^3 of rainwater to be pumped, for the Innovation Centre.

The current impasse highlighted in Section 2.3.11.4 regarding only promoting RWH rather than providing support to enable stakeholders to actually implement it (Ward *et al.,* 2009) seems unjustified when the operational CO_2 contribution, in this study, is no more than that of an appliance that is used everyday in many households. For example, the UK government currently promotes and supports the implementation of showers instead of baths to save water, whereas in fact annually less energy and CO_2 is emitted in heating the water to fill a bath in new houses – 161kg and 91 kg, respectively (EA, 2008a). These figures are based on a shower frequency of 0.75/p/d and bath frequency of 0.21/p/d, but the report acknowledges these assumptions are based on limited data for new dwellings and better data is required (the range identified is 0.21-1.1/p/d). The report further acknowledges that retrofitting an electric shower to a house that only has a bath (with water heated by a gas boiler) increases CO_2 emissions, due to the displacement of energy use from gas to electricity. This suggests the current trend of displacing bath use to shower use potentially results in an increase in energy consumption. It also may increase water use as it discourages bath water sharing, which is not considered in the EA (2008a) report. This discussion indicates that purely focusing on the energy consumption of RWH systems is perhaps inappropriate, as results are highly variable and dependent on a number of issues.

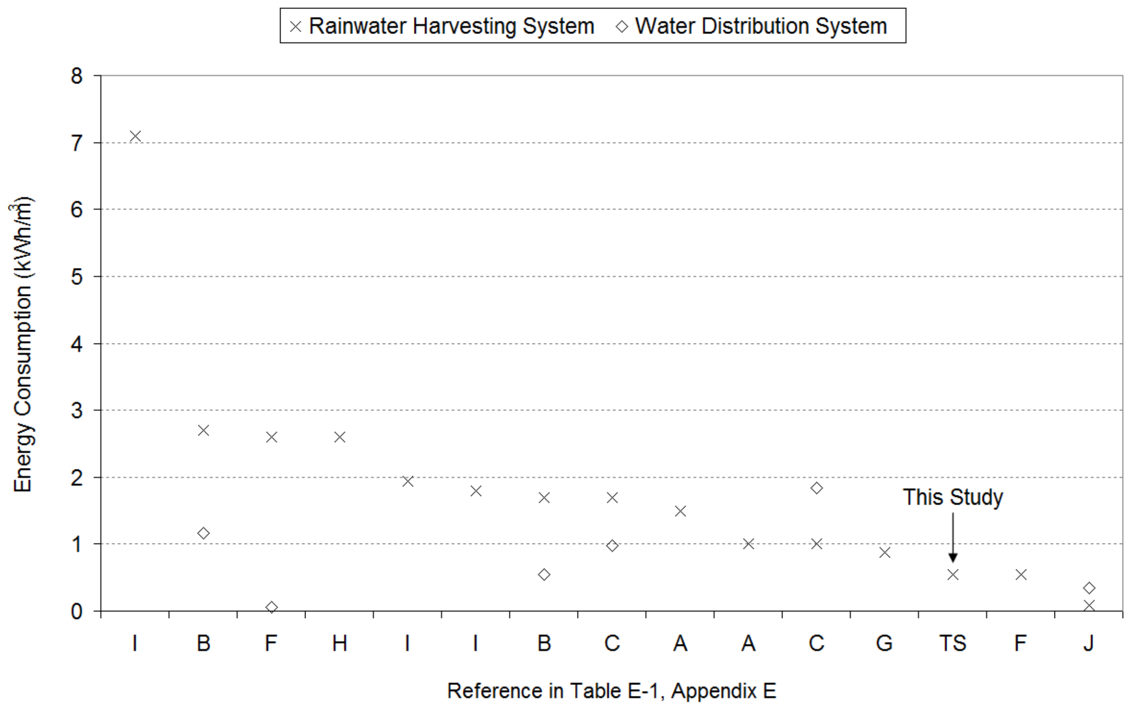


Figure 6.12 Variability of energy consumption values attributed to centralised WDS and decentralised RWH in a variety of locations

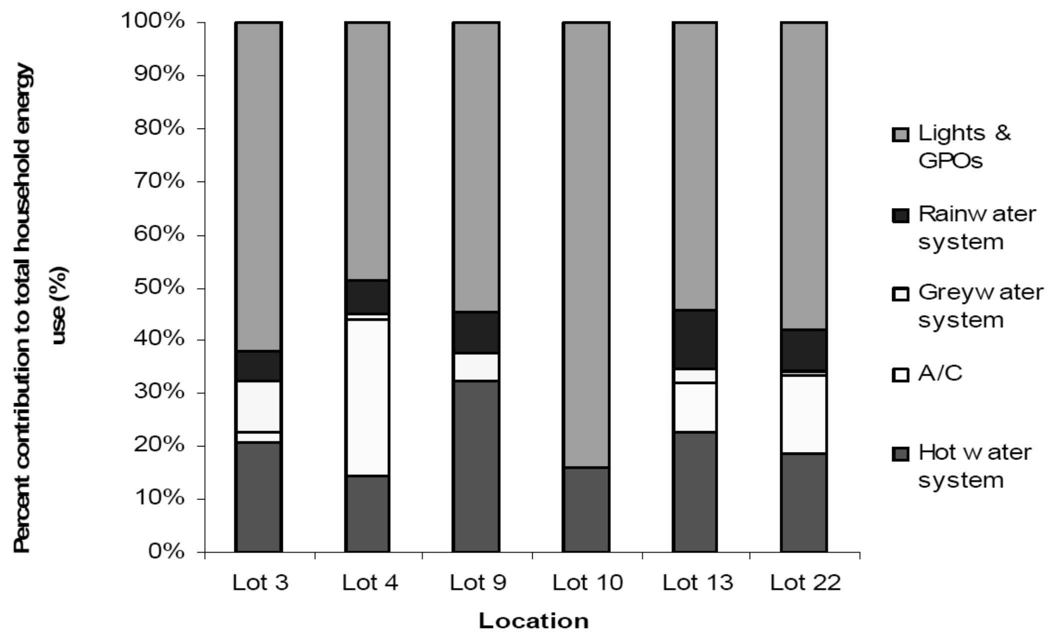


Figure 6.13 Comparison of sources of household energy consumption, including RWH (Gardner *et al.*, 2008)

6.3.6 Performance Evaluation: Summary and Key Messages

This section has described a programme of empirical data collection from a RWH system within an office building. It has also outlined a method for the calculation of energy consumption and carbon emissions from system pump operation that improves on previous methods. It has been identified that a RWH system within an office building provided an average water saving efficiency of 97% during a winter/spring period. Depression storage losses were minimal and runoff coefficients correspondingly high, suggesting that the system design runoff coefficient used was perhaps conservative. However, the main storage tank appeared to be sized sufficiently to allow overflow events to maintain an adequate turnover and quality of water (this is discussed in more detail in Chapter 5). Regarding periods of poor performance, it was shown that the slow resolution of faults led to long durations during which the system was performing sub-optimally. Financially, yearly total cost savings resulted in an estimated capital outlay payback period of 11 years. Additionally, application of the improved pump energy consumption method identified that the proportion of the office building's electricity consumption attributable to the RWH system is less than 1%, though this is likely due to the high proportion of electrical equipment used within the building.

Comparing the results of the performance evaluation with the design evaluation revealed that:

- Method 1 (the most detailed continuous simulation) provided the best approximation of actual RWH system performance;
- Using an over-optimistic demand results in over-optimistic estimated performance;
- Capital outlay payback periods are within the operational life of a RWH system, but maintenance costs could potentially extend this period substantially;
- The proportion of electricity used by a RWH system pump in an office building was marginal.

The key messages from this section are:

(1) The importance of monitoring and, for conventional systems, maintenance needs to be emphasized if systems are to function as intended;

(2) A transition to the use of more detailed design methods is required by those undertaking RWH system designs;

(3) The application of RWH to office buildings should be encouraged, due to the high water saving efficiency potential and low overall operational energy requirement;

(4) Greater innovation in the design and configuration of RWH systems is required to reduce capital outlay and maintenance commitments and costs, to increase the attractiveness of RWH to non-domestic building owners.

This section and the previous section have identified that the most detailed design method provided the best estimate of system performance. However, it was also identified that the careful representation of demand parameters is often not fully appreciated at the design stage, particularly for non-domestic buildings. The following section therefore describes the design and implementation of a flush counting programme within the Innovation Centre. This was undertaken in order to better quantify non-domestic WC demand patterns to facilitate an improved understanding of the effect of demand parameters on RWH system design.

6.4 Non-Domestic WC Demand Profiling and RWH System Design Comparison

Current RWH system design tools (Chapter 2, Section 2.3.8), generally utilise domestic WC demand data. However, concerns have been raised in using such data in the design of non-domestic systems. This concern was identified within the qualitative research undertaken within this thesis, where SMEs reported that the unusual frequency of demand of the micro-components within their business could not be quantified and resulted in RWH being shelved (Chapter 4). As RWH is currently primarily used for WC flushing in the UK, it was decided to undertake a RWH system design comparison, using domestic and non-domestic WC demand profiles. However, as limited research has been conducted on non-domestic WC demands, data collection and analysis activities had to be undertaken in order to devise a non-domestic WC demand profile. The Innovation Centre was used as the non-domestic monitoring location, as it has a RWH system, which could also be used as the model for the eventual system design comparison. Only WC demand is considered in the sections that follow, as waterless urinals are present in the Innovation Centre.

6.4.1 Measuring Non-Domestic WC Demand

In order to devise a non-domestic WC demand profile, monitoring equipment was required to collect data on how often water was used within a WC. Previous studies (Butler, 1991; That, 2005) utilised water consumption and/or wastewater discharge data to generate WC demand profiles. Measuring water consumption or wastewater discharge requires a meter to be fitted to an inlet or outlet on the chosen micro-component (for example, a WC pan). However, in the case of the Innovation Centre, fitting such meters to the WCs was not possible due to the construction of the wall panelling in which the WC pipe work was located. As the WC cistern was accessible, it was decided to use WC flush counting as a proxy for consumption/discharge and therefore a flush counting device was required. Despite a substantial amount of research, which included contacting researchers who had used flush counters in other studies, an off-the-shelf device could not be identified. Therefore the flush counting device used within this study was designed and developed with the assistance of a technician within the College of Engineering, Mathematics and Physical Sciences at the University of Exeter. In total, six units were manufactured so that multiple male and female WCs could be monitored within the Innovation Centre.

6.4.2 Flush Counter Design and Development

The flush counter consisted of a float switch connected to a digital interface (Figure 6.14), with integrated logging equipment (Figure 6.15). The logger was of the Enercom Multilog type supplied by the Buildings and Estate Services department. The components and wiring were securely contained within a standard indoor security box (Figure 6.14), to avoid the possibility of unauthorised tampering. This also made the unit easier to install, as well as robust enough to be transferred between monitoring sites, if required. A standard mains electrical power supply was used to feed the unit, as it was determined that using other power sources (such as car or leisure batteries) would be logistically difficult (as they would potentially require weekly recharging) and more costly. Specifications for the components used are located in Appendix E.

As water efficient dual-flush WCs are often now fitted as standard within the UK, the flush counter was developed to be able to distinguish between a full and a partial flush. When the WC's full flush button was depressed and the cistern fully emptied, the sensor travelled all the way down the spindle, logging one data point at the bottom water level (BWL, Figure 6.16). As the cistern filled, the sensor would travel up the spindle and upon reaching the top would register another data point. For a partial flush the sensor would travel down the spindle, but only reach half way (PFWL, Figure 6.16), therefore not registering a data point at the bottom. On travelling back up the spindle, it would register a data point at the top. Thus the downward data series indicated *full* flushes and the upward data series indicated the *total* number of flushes. A partial flush data series could be derived by simply subtracting the full flush data series from the total flush data series. The logger was wired to the float switch using four feeds and therefore stored the full and total flush data points as two separate data series within the logger.

Data for both flush series was in the form of a binary coding (one meaning a flush and zero meaning no flush) with both a time and date stamp attached to it. Data was downloaded to a laptop (Figure 6.15) from the logger via a serial port to USB cable using the interface illustrated in Figure 6.14. The Multilog Controller software was used to download and initially examine the data (the graphical user interface is illustrated in Figure 6.17), before exporting it as an ASCII file, which was then converted into a text file and transferred into Excel for more detailed analysis.

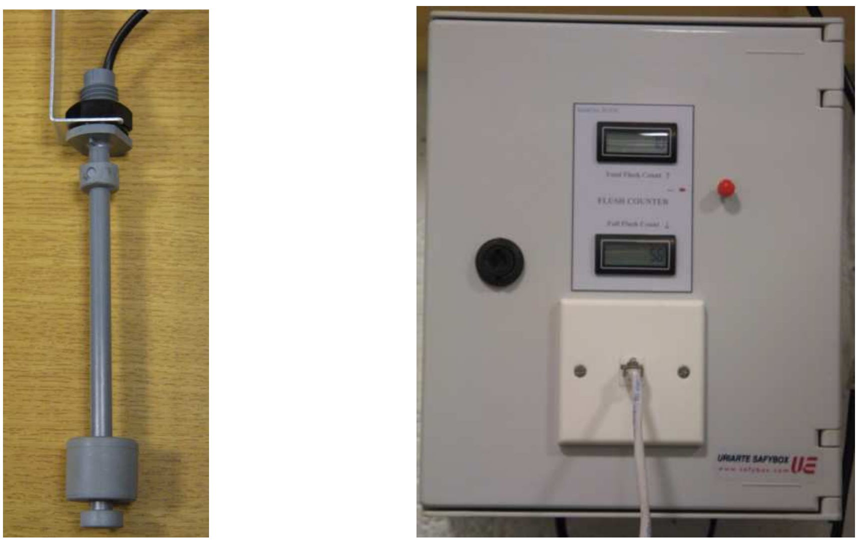


Figure 6.14 Float switch and digital interface of the flush counter

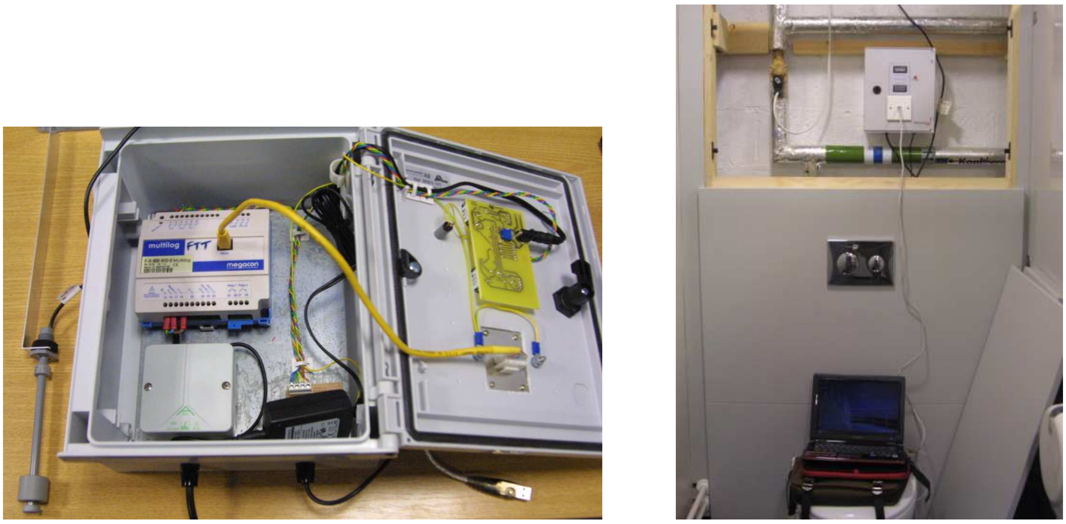


Figure 6.15 Internal components of the flush counter and the device *in situ*

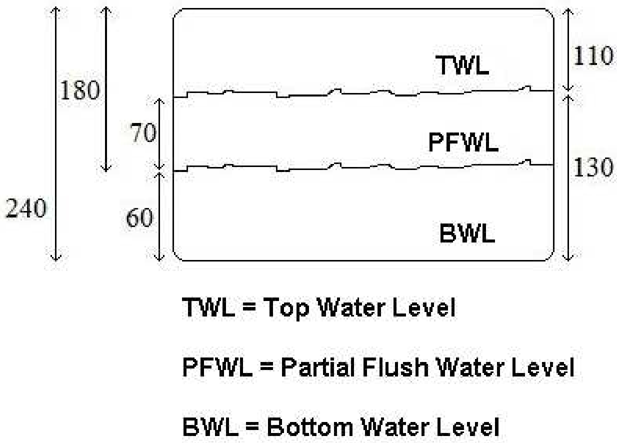


Figure 6.16 Dimensions of and water levels within the cisterns to which the flush counters were fitted (measurements in mm)

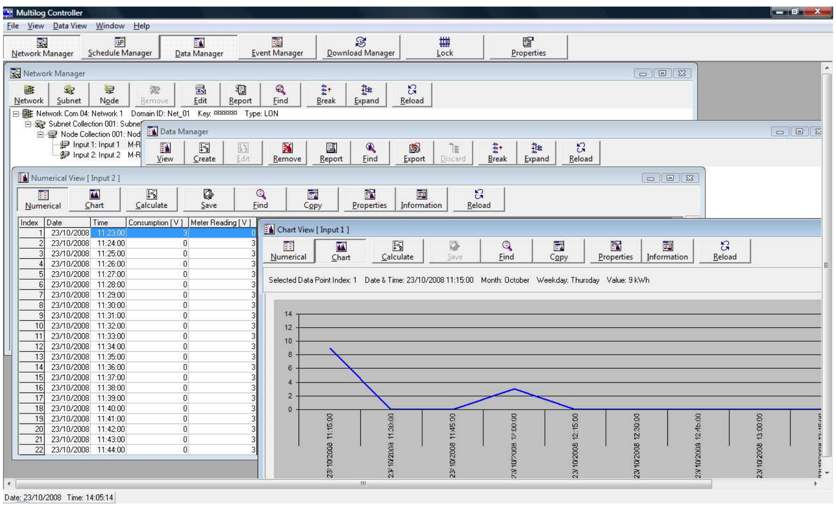


Figure 6.17 Graphical User Interface of the Multilog software

6.4.2.1 *Installation and Testing*

In total only five of the six units constructed were installed, as one of the loggers proved faulty and a replacement was not available. Three were fitted to toilet cisterns in WCs within female restrooms and two were fitted to male toilet cisterns (Figure 6.18). An electric socket of the appropriate voltage was fitted within the enclosed space above the cisterns by the University's electrical installations team. The flush counters were fitted within this space, so that they would not be visible to the WC users and therefore not bias the flusher's behaviour. The float switch was then installed in the cistern and held in place by a plastic-coated steel plate (to withstand exposure to water over a long duration). Each unit was then configured using the Multilog software.

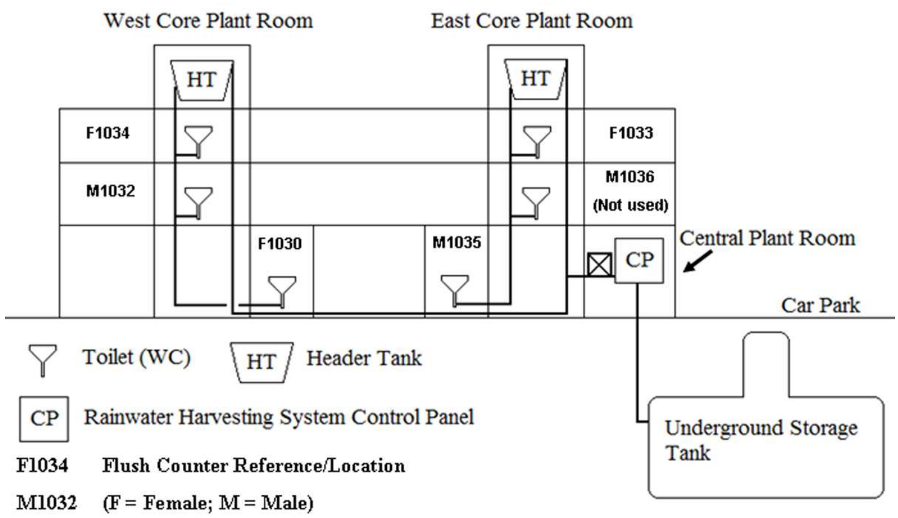


Figure 6.18 Schematic of the locations of the flush counters within the Innovation Centre

After the flush counters were installed a two week pilot study period was conducted for testing, proving and commissioning the flush counters. Testing involved:

- Ensuring the correct data series was logged when either the full or partial flush button was depressed;

- Ensuring the float switch did not rebound when the cistern refilled to prevent false multiple flushes from registering.

Initially data was logged at fifteen minute intervals and then four minute intervals to identify any issues with logging or downloading. It was discovered that the loggers would be able to hold one month's data at a resolution of fifteen minutes, but would only be capable of holding one week's data at a time step of four minutes before a download was required. If the interval between downloads exceeded the maximum time, depending on time step, the logger would simply over-write the data. A further test was conducted at the one minute interval and it was identified that the data would require daily downloading. A sub-minutely interval was not possible with the logging equipment available.

As the water quality sampling schedule (Chapter 5) was primarily weekly, it was decided to log data at four minute intervals for the majority of the flush monitoring period, so that downloads could be undertaken alongside sampling activities. However, it was decided to conduct one week of monitoring at a one minute interval, in order to gather a richer dataset. The four minute data was collected between the 31st of March and the 3rd of June 2009 and the one minute data between the 8th and 12th of June 2009. As far as could be identified by the author, there were no particularly unusual events that occurred during these periods, which would have had an effect on the flushing habits of the Innovation Centre's occupants.

6.4.2.2 Data Integrity and Flush Counter Limitations

Figure 6.19 illustrates the format in which the data was recorded by the flush counter loggers, as a text file imported into Excel. Preliminary data analysis was performed using Excel spreadsheets and generating pivot tables (Appendix F). These produced summaries of the number of flushes per time step for each flush counter for both full and partial flushes.

On examination of the data, some irregularities were discovered, which were not identified during pilot testing. In deriving the partial data series the full data series is subtracted from the total data series. Thus where the total data series, has registered a '1' and there is not a '1' in the full data series a partial is definitely indicated.

However, for some flush counter readings, when the full data series was subtracted from the total data series, a negative figure was derived. This is exemplified in Table 6.14 for flush counter F1030, where both normal and erroneous data point examples are illustrated.

Table 6.14 Example of normal and erroneous data from flush counter F1030

FC F1030	DATE	TIME	TOTAL	FULL	PARTIAL
NORMAL	24/02/09	11:48:00	1	0	1
NORMAL	24/02/09	18:24:00	2	1	1
NORMAL	25/02/2009	16:56:00	1	0	1
NORMAL	27/02/2009	07:08:00	3	0	3
ERRONEOUS	25/02/2009	17:00:00	0	1	-1
ERRONEOUS	26/02/2009	08:48:00	1	4	-3
ERRONEOUS	05/03/2009	11:12:00	0	2	-2
ERRONEOUS	06/03/2009	08:36:00	1	2	-1

Two observations were made:

1)
- A reading does not show under total;
- A reading shows under full;
- This results in the partial being negative.

2)
- A reading shows under total;
- The reading under full is in excess of the total;
- This results in the partial being negative and either equal to or in excess of the total, but less than the full.

In order to determine the source of these errors, testing was undertaken using FC F1034 to try to replicate them under controlled conditions. Several scenarios were trialled, which represented proposed explanations to (1) and (2):

i. Too rapid repeat flushing:
ii. Filling completes in a different time step.

These scenarios were tested by:

- Pressing the full and partial flush buttons in rapid succession to see how many full and total flushes registered in a particular time step;
- Timing how long a cistern took to fill after a full flush, to see if it was longer than the time step.

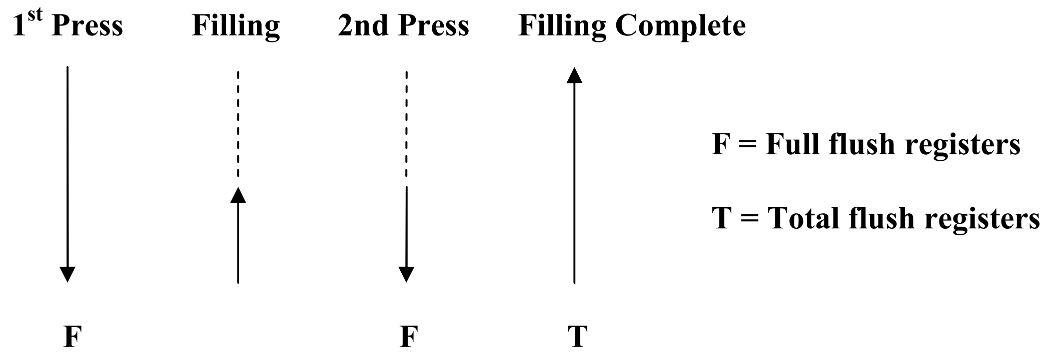
1	Network Description	Network 1			
2	Network Collection	Com 6			
3	Network Domain	Net_01			
4	Subnet Description	Subnet 1			
5	Subnet Collection	1			
6	Node Description	R1030			
7	Node Collection	1			
8	Node ID	576267100			
9	Input Description	Input 1			
10	Input Collection	1			
11	Meter Constants	1			
12	Transformer Constants	1			
13	Max Meter-Reading	999999999			
14	Data Unit	l/s			
15	Storage Method	Minutely			
16	Storage Duration	4			
17					
18	Current Meter-reading	03/06/2009	09:43:28	792	
19					
20	Number Of Data Points: 2673				
21	Includes Data	26/05/2009 23:28:00 - 03/06/2009 09:36:00 85 kB			
22					
23	Index	Date	Time	Consum	Meter Reading [l/s]
24					
25	1	27/05/2009	11:12:00	1	752
26	2	27/05/2009	11:16:00	0	753
27	3	27/05/2009	11:20:00	0	753
28	4	27/05/2009	11:24:00	0	753
29	5	27/05/2009	11:28:00	0	753
30	6	27/05/2009	11:32:00	0	753
31	7	27/05/2009	11:36:00	0	753
32	8	27/05/2009	11:40:00	0	753
33	9	27/05/2009	11:44:00	0	753
34	10	27/05/2009	11:48:00	0	753
35	11	27/05/2009	11:52:00	0	753
36	12	27/05/2009	11:56:00	0	753
37	13	27/05/2009	12:00:00	0	753
38	14	27/05/2009	12:04:00	0	753
39	15	27/05/2009	12:08:00	0	753
40	16	27/05/2009	12:12:00	1	753
41	17	27/05/2009	12:16:00	0	754
42	18	27/05/2009	12:20:00	0	754
43	19	27/05/2009	12:24:00	0	754
44	20	27/05/2009	12:28:00	0	754
45	21	27/05/2009	12:32:00	0	754
46	22	27/05/2009	12:36:00	0	754
47	23	27/05/2009	12:40:00	0	754
48	24	27/05/2009	12:44:00	0	754
49	25	27/05/2009	12:48:00	0	754
50	26	27/05/2009	12:52:00	0	754
51	27	27/05/2009	12:56:00	0	754
52	28	27/05/2009	13:00:00	0	754
53	29	27/05/2009	13:04:00	0	754
54	30	27/05/2009	13:08:00	0	754
55	31	27/05/2009	13:12:00	0	754
56	32	27/05/2009	13:16:00	0	754
57	33	27/05/2009	13:20:00	0	754
58	34	27/05/2009	13:24:00	0	754
59	35	27/05/2009	13:28:00	0	754
60	36	27/05/2009	13:32:00	2	754

Figure 6.19 Excerpt of a raw data file for input 1 (total flushes) for flush counter F1030

Multiple button pressing revealed that when a cistern had partially filled after one full flush and the button was pressed again, another full flush registered. If the cistern was left to fully fill the second time, the total would only register one. If the button was pressed again before the cistern had completed filling, a further full flush was registered. This is illustrated in Figure 6.20. Thus if the full button was pressed during the refilling of the cistern, the cistern would empty and extra full flushes would be recorded, in excess of the total flush number. In the example, button pressing results in two full flushes and one total flush. Subtracting the former from the latter results in a partial flush number of -1: this is obviously not feasible and provides an explanation for observation (2).

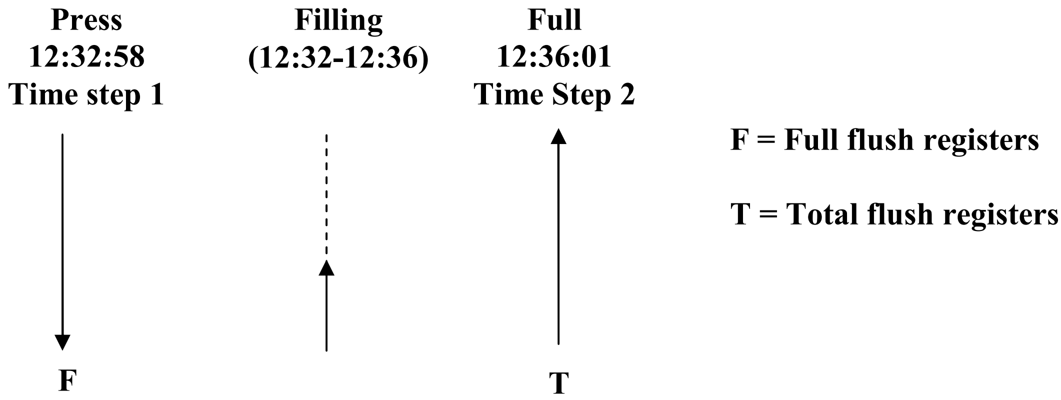
Timing the filling duration of the cistern revealed that if the full button was pressed towards the end of a time step, the full data point would register in one time step and the total data point would register in a subsequent time step. This is exemplified in Figure 6.21, which shows the filling process and how it is recorded in the data series. In this example, the total ('T') indicated in time step 2 (12:36) arises from the cistern completing filling from a full flush ('F') in time step 1 (12:32). However, subtracting the full series from the total series, to yield the partial series, results in an indication of a partial flush. Thus in this case the final data point appears to be potentially indicative of either a full flush in the previous time step that is still refilling in the next time step *or* a partial flush. The number of time steps between the full and the total flushes registering varied, depending on the overall time step length i.e. one minute or four minutes. It did not affect the fifteen minute time step as the cistern filled within this duration. For the one minute interval the total flush could register up to three intervals after the full flush. For the four minute interval this was generally one interval after. This provides an explanation for some incidences of observation (1). A combination of this effect and the multiple pressing effect resulted in the number of full flushes in a time step in excess of the total flush number – providing further explanation for observation (2) where full is greater than total.

During error replicability testing, multiple pressing (whether due to double flushing, or several individuals flushing consecutively) within a time step was also shown to prevent a total from registering alongside a full, in some cases. However, this does not affect the partial data series, as if total is less than full, there is nothing to subtract to give a partial figure i.e. where there is no total present, a definite full is indicated.



	T	F	P (T-F)
12:32	1	2	-1

Figure 6.20 The effect of multiple button pressing within a time step



		T		F		P (T-F)	
Time Step 1	12:32	0		1	✓	-1 (P = 0)	
Time Step 2	12:36	1	✓	0		1	X

Figure 6.21 The ambiguity caused by the refilling of a flush across two (or more) time steps

It was also identified that the cistern filling mechanism, which was controlled by a solenoid valve, was connected to the passive infrared (PIR) sensor that controlled the lights within the restroom. This was not known when the flush counters were designed, installed and tested. Testing revealed that if the cistern was part way through refilling when the lights went out, the filling would cease. When a person then entered the restroom and the PIR triggered the lights to come on, the cistern would complete filling. Consequentially, the full data point was registered in one time step and the total data point registered in a following time step. This provided an additional explanation for some occurrences of observation (1).

6.4.2.3 Summary of Flush Counter Limitations

Testing was undertaken to replicate errors discovered within the data. The following sources of error were identified, which illustrate the limitations of the flush counters:

- Multiple button pressing within a time step;

- Inability to distinguish between multiple individuals flushing consecutively within a time step and multiple single-individual consecutive flushes ('double flushing');

- Cistern refilling across multiple time steps;

- Connection between the cistern solenoid valve and the restroom lights PIR.

6.4.2.4 Processing the Data

The limitations of the flush counters identified in the previous sections resulted in the need to process the data before it could be used to develop a non-domestic diurnal WC demand profile. The effects that produced a superfluous negative partial reading were unambiguous (i.e. attributable to a single cause) and could be taken into account when processing the data. They were easily removed from the data series using a simple 'IF' statement within Excel and their removal did not affect any other aspect of the data. However, the filling across two time steps and PIR interruption effects led to a greater ambiguity in the data series and incidents of this error were more difficult to identify and eliminate. Due to the inconsistency and interaction of the errors outlined above the data was manually processed to remove any spurious readings.

The rules used to manually process the data were:

- Both data sets – reduce full flushes to equal total flushes where incidents of multiple flushing are confirmed i.e. if the total in a time step is two and the full is seven, this indicates five flushes which were most likely multiple flushing;

- One Minute Data - remove data points when a full in one time step is proceeded in *one of the next three time steps* by a total i.e. removal of a full data point if it is not anchored to a total in the same time step, as it could be misinterpreted as a partial flush;

- Four Minute Data - remove data points when a full in one time step is proceeded in *the next time step* by a total i.e. removal of a full data point if it is not anchored to a total in the same time step, as it could be misinterpreted as a partial flush.

After processing the data, the number of removed data points was calculated and a percentage of the total number of full data derived, to quantify the potential errors in the raw datasets. These are summarised in Table 6.15, which illustrates that in general the error caused by the flush counter limitations was around 10%, depending on the flush counter. As would be expected, the degree of error in the one minute time step data set was higher, as there was greater potential for the refilling cistern to complete in a different time step. Less multiple flushes were registered in the one minute data set, with the exception of flush counter F1033. This may indicate a particular problem with the flush calibration i.e. users of the WC are required to press the button excessive times in order to achieve the required level of cleaning performance.

Table 6.15 Quantifying the error associated with the flush counter limitations

Flush Counter Reference	Time Step	Total Number of Full Data Points (after multiple flushes rectified)	Multiple Flushes Rectified	% Error	Number of Data Points Removed	% Error
F1030	One Minute	48	0	**0**	3	**6.3**
M1032	One Minute	120	0	**0**	6	**5**
F1033	One Minute	138	5	**3.6**	14	**10.1**
F1034	One Minute	110	0	**0**	2	**1.8**
F1035	One Minute	18	0	**0**	0	**0**
F1030	Four Minute	596	14	**2.4**	4	**0.7**
M1032	Four Minute	867	29	**3.5**	2	**0.2**
F1033	Four Minute	999	40	**4.0**	7	**0.7**
F1034	Four Minute	583	25	**4.3**	2	**0.3**
F1035	Four Minute	98	3	**3.0**	0	**0**

6.4.2.5 Raw and Processed Data Comparison

In order to identify the potential impact of the sources of error on the data, two data sets were compiled for each time step duration – one containing the erroneous readings and one processed to remove them (hereafter referred to as 'raw' and 'processed', respectively). These were then compared to highlight any discrepancies caused by the flush counter limitations outlined in the previous section.

6.4.2.6 One Minute Raw and Processed Data Comparison

Figure 6.22 and Figure 6.23 illustrate the overall daily WC full and partial flush data for the raw and processed data for all flush counters at the one minute interval. The sources of error outlined above are evident in the raw data as the frequency of negative readings. The use of this data in subsequent analyses would not be appropriate due to its lack of robustness. The improvement evident in the processed data permits subsequent analyses, as the reliability of the data is increased by removal of the erroneous data points. Consequentially only the processed full and partial flush data (Figure 6.24) is fully analysed in the sections that follow.

6.4.2.7 Four Minute Raw and Processed Data Comparison

Figure 6.25 and Figure 6.26 illustrate the overall daily WC full and partial flush data for the raw and processed data for all flush counters at the four minute interval. The sources of error outlined above are evident in the raw data as the frequency of negative readings. The use of this data in subsequent analyses would not be appropriate due to its lack of robustness. The improvement evident in the processed data permits subsequent analyses, as the reliability of the data is increased by removal of the erroneous data points. Consequentially only the processed full and partial flush data (Figure 6.27) is fully analysed in the sections that follow.

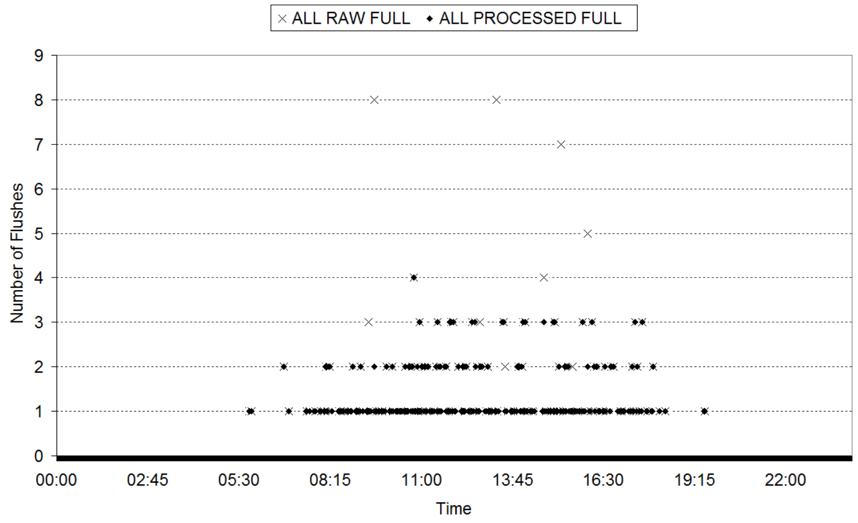


Figure 6.22 The difference between the raw and processed flush counter data for the full flush data series (all flush counters) at the one minute time step

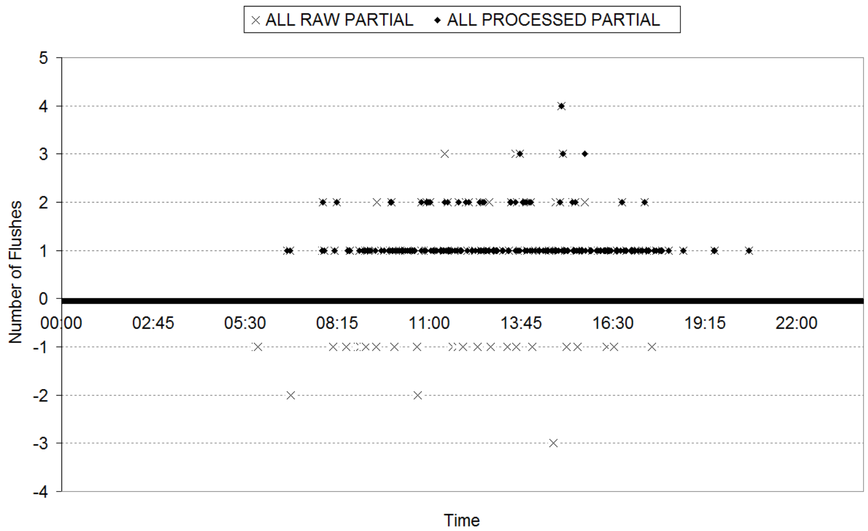


Figure 6.23 The difference between the raw and processed flush counter data for the partial flush data series (all flush counters) at the one minute time step

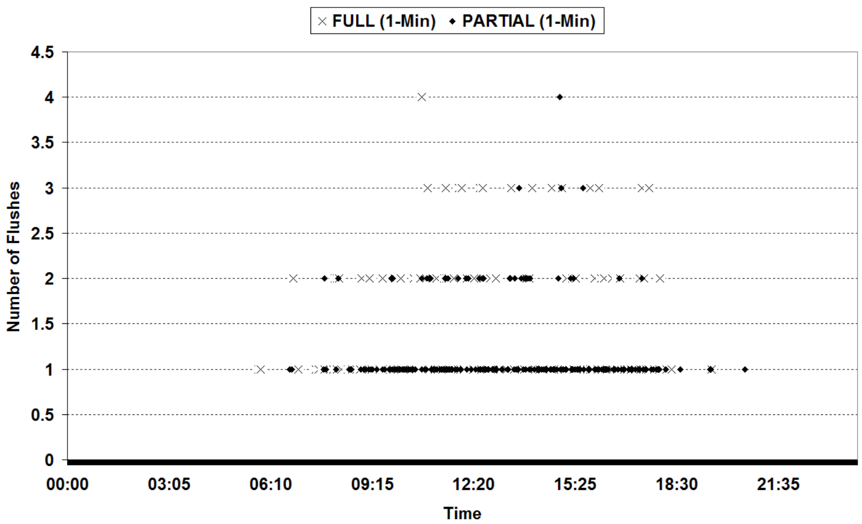


Figure 6.24 The processed flush counter data for the full and partial flush data series (all flush counters) at the one minute time step

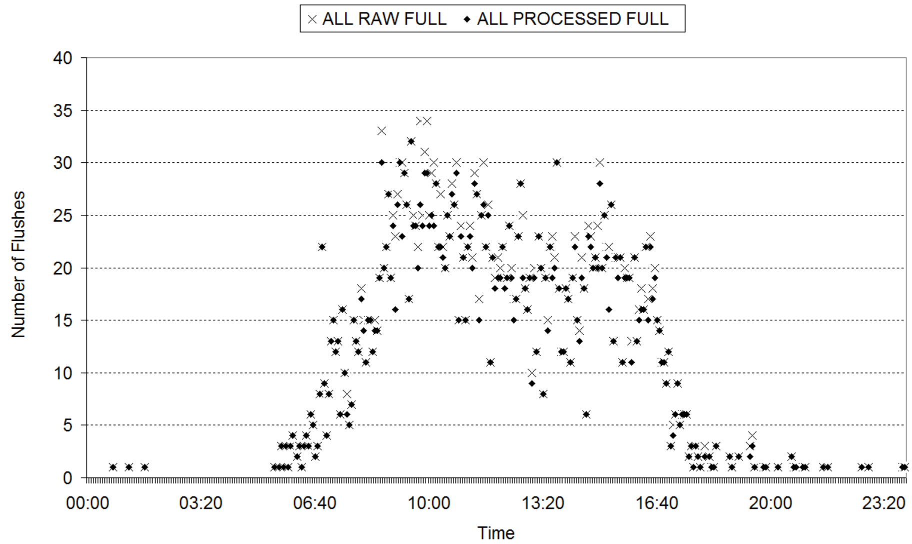


Figure 6.25 The difference between the raw and processed flush counter data for the full flush data series (all flush counters) at the four minute time step

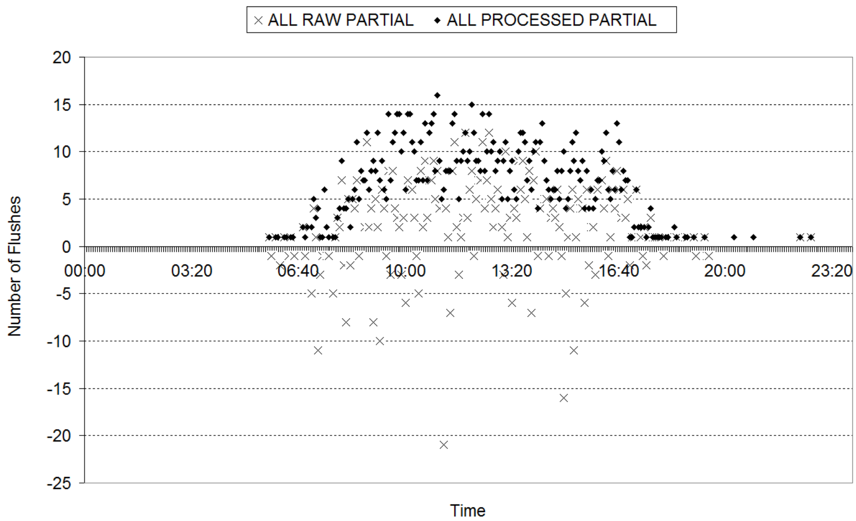


Figure 6.26 The difference between the raw and processed flush counter data for the partial flush data series (all flush counters) at the four minute time step

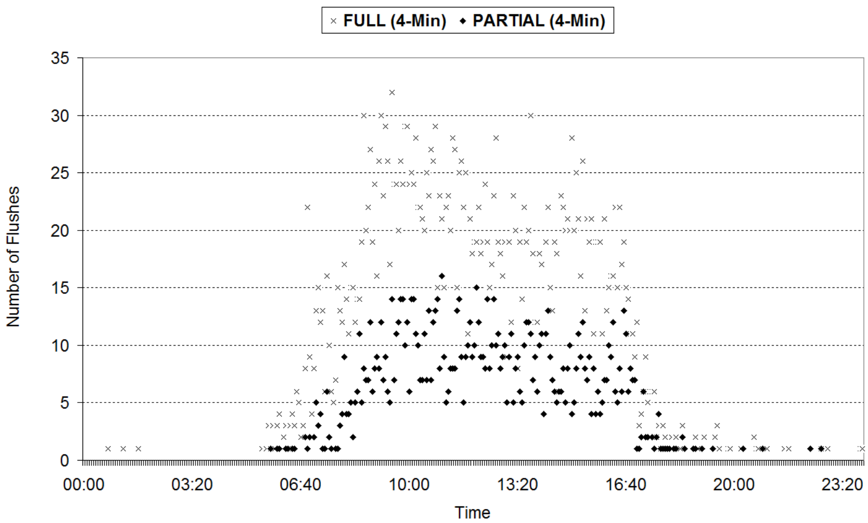


Figure 6.27 The processed flush counter data for the full and partial flush data series (all flush counters) at the four minute time step

6.4.3 One Minute Processed Data Analysis

Before constructing frequency profiles of the one minute flush counter data, in order to derive probability distributions, it was important to examine the individual flush counter data. This ensured that any subsequent compiling of the data was based on suitable assumptions. For example, if there was a significant difference between the flushing habits of males and females, aggregating the data for both genders could produce a distorted profile. The individual flush counter profiles were examined to identify any differences or similarities.

Figure 6.28 illustrates the percentage of full and partial flushes for each flush counter and overall. 61% of flushes recorded across the five counters were full and 39% partial flushes. A 1-tailed hypothesis was established (there were more full than partial flushes) and a paired-sample T-test (as the same flush counters were used to record full and partial flushes) was conducted using SPSS. This revealed that overall there was not a significant difference between the number of full and partial flushes ($t = 1.784$, $P = 0.05$ (1-tailed)). The difference was significant at the $P = 0.07$ level, however.

This ratio appeared to be approximately the same across all the flush counters, with apparently very little variation between male and female flush counters. This was confirmed with the use of an independent-sample T-test for a 2-tailed hypothesis (there is no difference between full and partial flushes for males and females). This resulted in no significant difference between the male and female flush counters for both full and partial flushes (Table 6.16). The data was assumed to have a normal distribution, which was confirmed by Levene's Test for Equality of Variances (which did not breach the $P < 0.05$ level).

Table 6.16 T-test results for gender differences of full and partial flushing

Type of Flush	F*	p*	t*	p *
Full	5.891	0.094	-0.417	0.705
Partial	0.024	0.886	-1.028	0.380

*F = the Levene Test statistic; p = significance level; t = the Student's T-test statistic

As there was not a significant difference between the full and partial flushes of the male and female flush counters, it was decided that it would be appropriate to combine the data for further analysis.

A final observation concerned the slight difference between the male flush counters, M1032 and M1035, with the former having a slightly higher percentage of full flushes. This was not anticipated, as M1032 is in a restroom that has waterless urinals. It was anticipated that full flushes would be less for this WC than for M1035. A possible explanation is that M1032 receives visitors from both the Innovation Centre's conference and café facilities (M1035 does not) and this led to a higher overall level of full flushing.

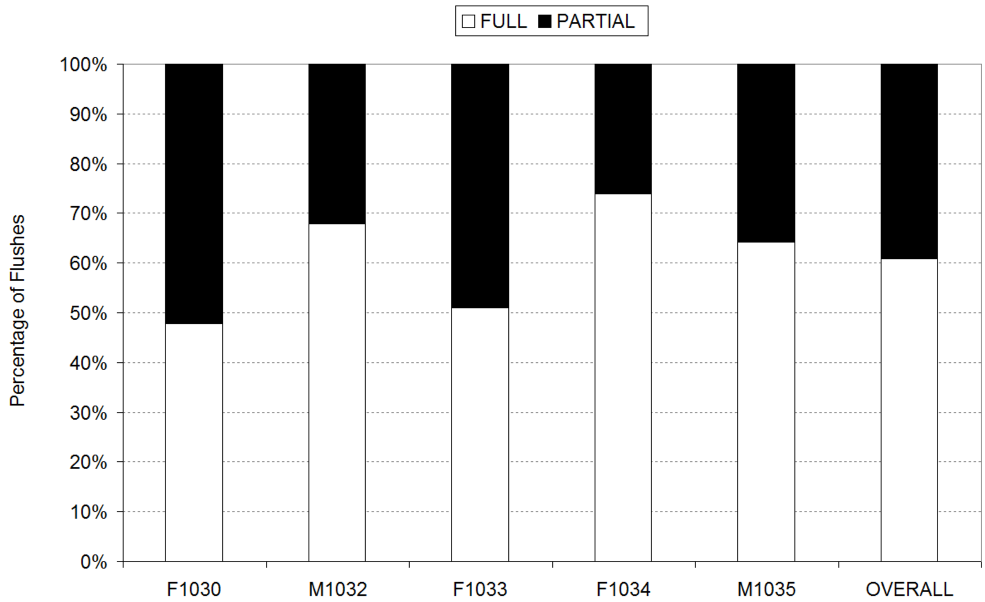


Figure 6.28 Inter-counter/male (M) and female (F) differences between full and partial flushing at the one minute time step

6.4.4 One Minute Diurnal Rolling Frequency Profiles

Figure 6.279 illustrates the overall total full and partial flushes in each one minute time step for all of the flush counters. However, it does not adequately identify the underlying trends in the data. In order to identify these, the use of a rolling average was employed, inline with that undertaken by That (2005) for domestic micro-component analysis. As the primary data was at the one minute interval, it was decided to examine the data using a rolling average of 10, 30 and 60 minutes in order to assess the smoothing affect of the increasingly larger time averaging. Firstly the data for full and partial flushes was totalled at 10, 30 and 60 minute intervals. These totals were then divided by 5 (the number of flush counters) to yield the average number of flushes in a 10, 30 or 60 minute interval. The results are illustrated in Figure 6.29 (A, B and C, respectively), which are shown on the same page for ease of comparison. It is evident from the three graphs that there are two distinct peaks for full flushing – the first between 10am and 1pm and the second between 3pm and 6pm. However, this is not so well defined for partial flushing, which shows a more even distribution throughout the day, although there is a marginal peak between 11am and 12pm, in rough agreement with the full flush peak. When comparing this profile to the well-established domestic WC profile (Figure 2.18, Section 2.3.7), it can be seen that the two contrast distinctly. The domestic profile has a morning peak between 7am and 9am and an evening peak between 6pm and 8pm. This will be explored in more depth later in this chapter (Section 6.4.7), alongside the four minute data diurnal profile.

6.4.5 Four Minute Processed Data Analysis

Before constructing frequency profiles of the four minute flush counter data, in order to derive probability distributions, it was important to examine the individual flush counter data. This ensured that any subsequent compiling of the data was based on suitable assumptions. For example, if there was a significant difference between the flushing habits of males and females, aggregating the data for both genders could produce a distorted profile. The individual flush counter profiles were examined to identify any differences or similarities.

Figure 6.30 illustrates the percentage of full and partial flushes for each flush counter and overall. Overall, 71% of flushes recorded across the five counters were full flushes and 29% partial flushes. A one-tailed hypothesis was established (there were more full than partial flushes) and a paired-sample T-test (as the same flush counters were used to record full and partial flushes) was conducted using SPSS. This confirmed that overall there *was* a significant difference between the number of full and partial flushes, with more full flushes than partial flushes ($t = 3.773$, $P = 0.01$ (1-tailed)).

This ratio appeared to be approximately the same across all the flush counters, with apparently very little variation between male and female flush counters. This was confirmed with the use of an independent-sample T-test for a two-tailed hypothesis (there is no difference between full and partial flushes for males and females). This resulted in no significant difference between the male and female flush counters for both full and partial flushes (Table 6.17). The data was assumed to have a normal distribution, which was confirmed by Levene’s Test for Equality of Variances (which did not breach the $P < 0.05$ level).

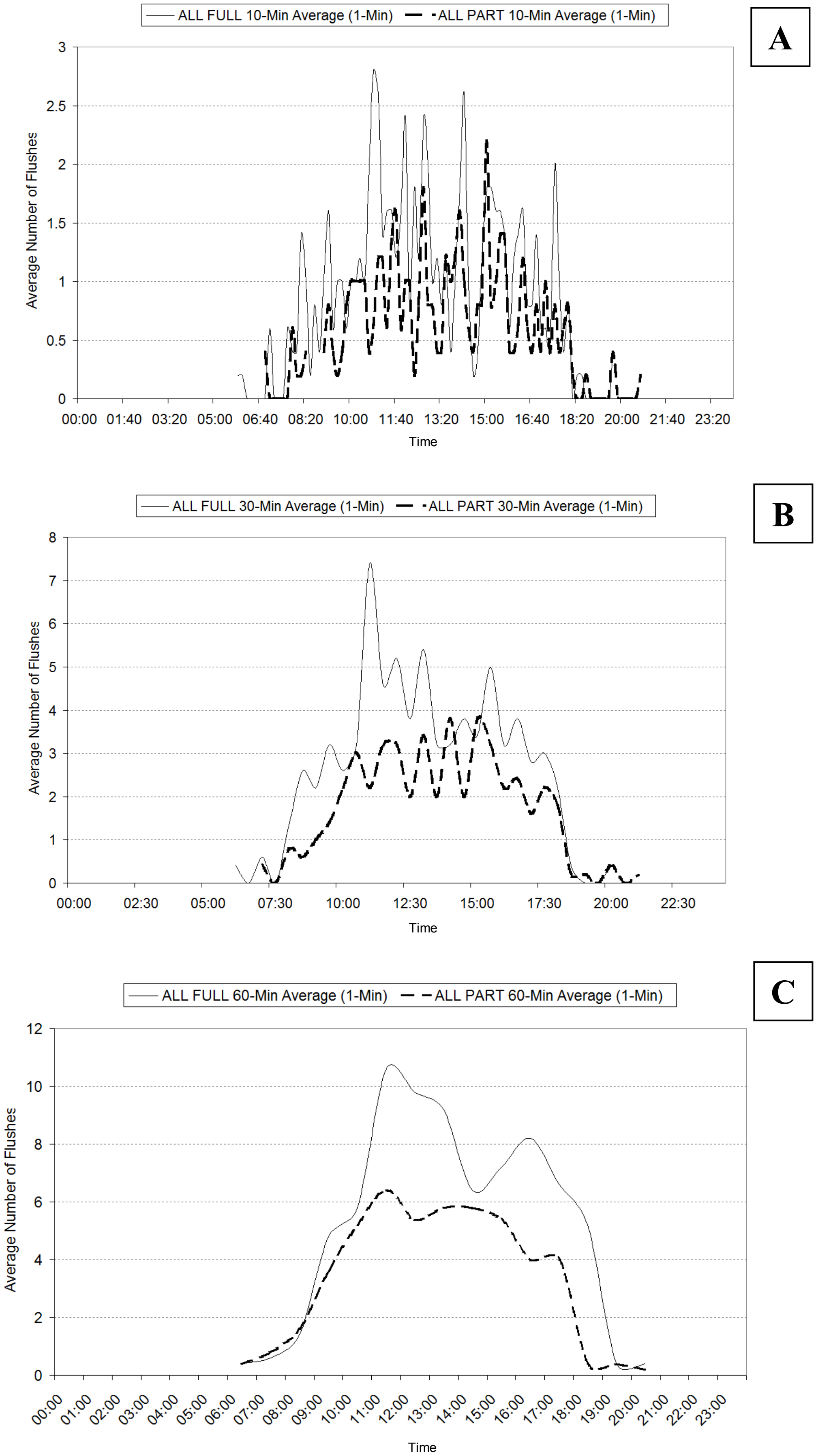


Figure 6.29 Diurnal full and partial flush average frequency profiles (10, 33 and 60 minutes) for data at the one minute time step for 7 days

Table 6.17 T-test results for gender differences of full and partial flushing

Type of Flush	F*	p*	t*	p*
Full	6.539	0.083	-0.735	0.516
Partial	0.009	0.931	-0.633	0.571

*F = the Levene Test statistic; p = significance level; t = the Student's T-test statistic

As there was not a significant difference between the full and partial flushes of the male and female flush counters, it was decided that combining the data was appropriate.

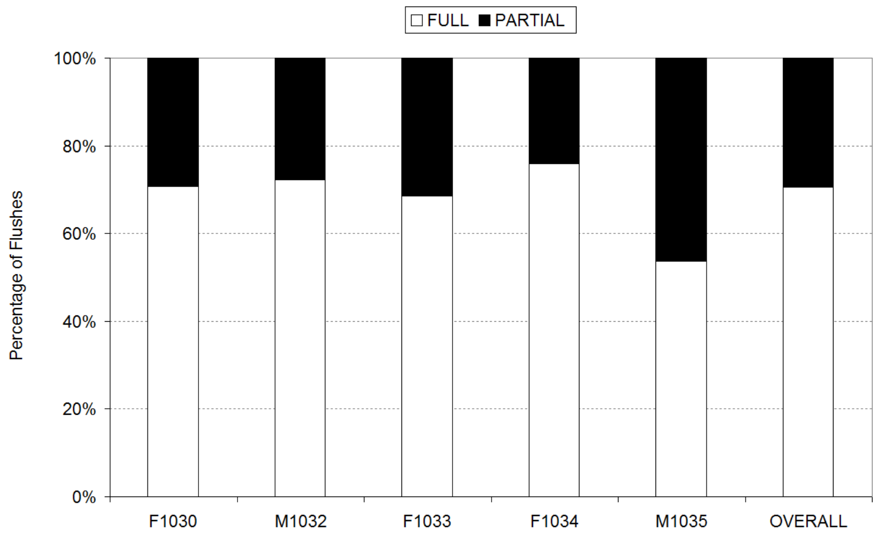


Figure 6.30 Inter-counter/male (M) and female (F) differences between full and partial flushing at the four minute time step

6.4.6 Four Minute Diurnal Rolling Frequency Profiles

Figure 6.27 illustrates the overall total full and partial flushes in each four minute time step for all of the flush counters. However, it does not adequately identify the underlying trends in the data. In order to identify these, the use of a rolling average was employed, as described in Section 6.4.4, but for 12, 36 and 60 minute intervals.

The results are illustrated in Figure 6.31 (A, B and C, respectively), which are shown on the same page for ease of comparison. It is evident from the three graphs that the patterns identified in the one minute data are corroborated by the four minute data. Those patterns being:

- A full flush peak between 10am and 1pm;
- A second full flush peak between 3pm and 6pm;

- A less well defined peak for partial flushing;
- A marginal partial flush peak between 11am and 12pm.

6.4.7 Non-Domestic WC Demand Frequency Profile

The one and four minute average hourly frequency profiles were averaged across the 5 and 46 day monitoring periods (these figures do not include weekends as the building was presumed to be predominantly empty). They were then combined, resulting in the composite full and partial flush frequency profiles illustrated in Figure 6.32. These were multiplied by 6L and 3L to yield the average volume consumed for a full and partial flush (Figure 6.33). The profile shape of the domestic profile has been superimposed onto the non-domestic profile to highlight the differences between them, but the values used are not actual values (as these were not available): it is shown for illustrative purposes only. The total and daily average flush numbers are summarised in Table 6.18. For the one minute data a ratio of 1.57:1 full to partial flushes was calculated and for the four minute data a ratio of 2.44:1, resulting in an average ratio of 2:1.

Table 6.18 Total and Average Daily Number of Flushes for the Innovation Centre

	Total Flushes	Average Daily Flushes	Ratio
1-Min Full (5 days)	385	77	1.57:1
1-Min Partial (5 days)	247	49	
4-Min Full (46 days)	3012	66	2.44:1
4-Min Partial (46 days)	1258	27	

As discussed in Section 6.3.2.1, data from the BMS permitted analysis of sub-daily flush volumes. A daily profile at hourly intervals was derived by totalling the 30 minute data and averaging it across the five day monitoring period. However, as the frequency of flushing was different between the two data sets the data required transformation in order to plot the two data sets on the same chart. The most common transformation for positive data is the use of a common multiplication factor and the natural log (Robson, 2002). Therefore the volumes derived from the flush counter data set were transformed by multiplying by 10 and the natural log applied to both datasets. The resultant values are plotted in Figure 6.34, alongside the domestic profile (not actual values, illustrative purposes only). It can be seen that the profiles derived from the flush counter data and the volume consumed data are closely aligned and the mid-morning and early evening peaks are reflected in both. The differences to the domestic profile are thus reinforced by both datasets.

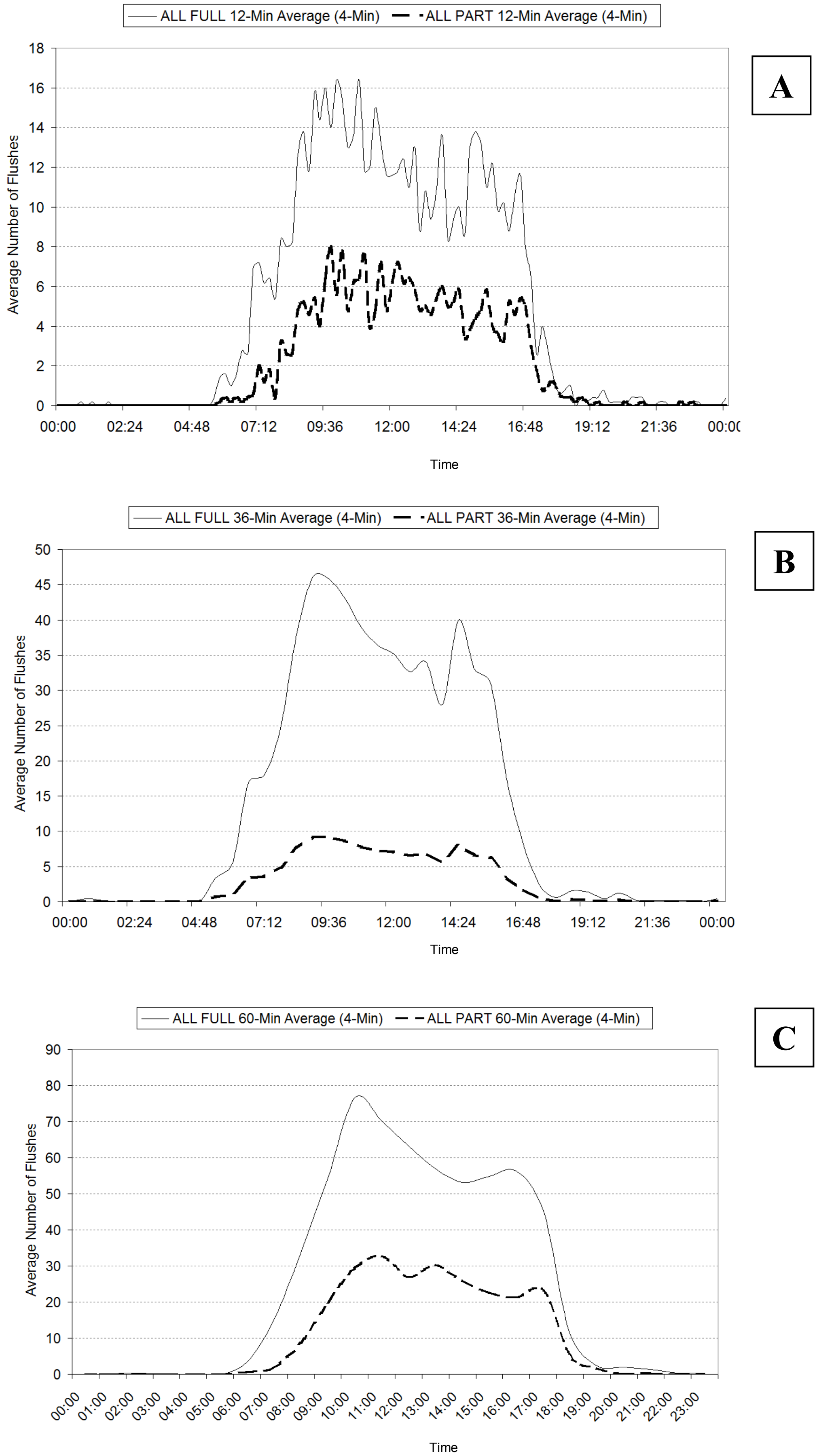


Figure 6.31 Diurnal full and partial flush average frequency profiles (12, 36 and 60 minutes) for data at the four minute time step for 46 days

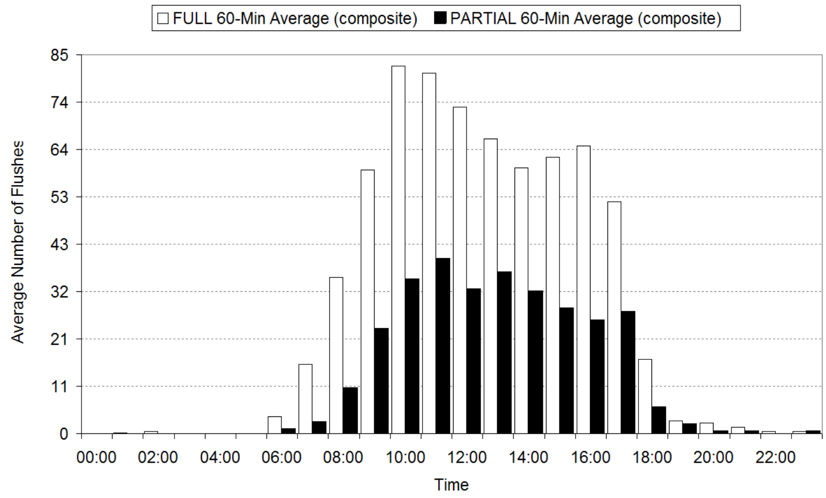


Figure 6.32 Diurnal full and partial flush frequency profiles averaged across five flush counters and 46 days

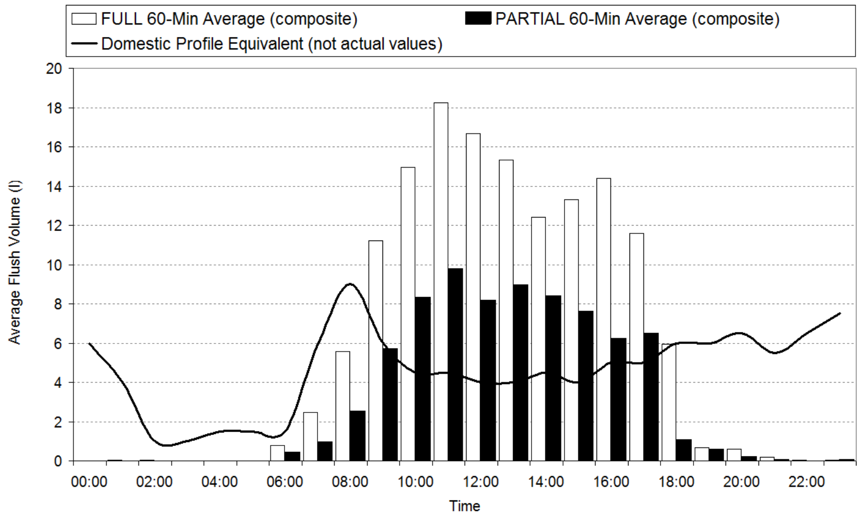


Figure 6.33 Diurnal full and partial flush volume consumed profiles averaged across five flush counters and 46 days

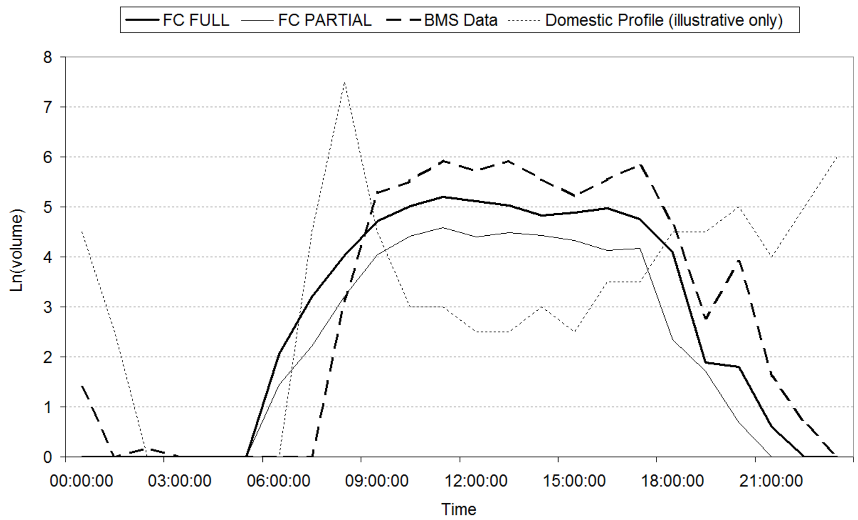


Figure 6.34 Comparison of non-domestic WC daily use profiles derived from flush counters (FC) and total volume consumed data (BMS) from the Innovation Centre, alongside an illustrative domestic demand profile

6.4.8 Non-Domestic RWH System Design Comparison

RWH systems designed for non-domestic buildings using a domestic demand profile have the potential to substantially under or over-estimate tank sizes, due to the variability of weekly and daily peaks resulting in different timings as to when the tank may be empty or full. In order to determine the impact of this effect, a design comparison was undertaken.

The initial aim was to utilise the sub-daily non-domestic demand profile determined in the previous section within an existing public domain RWH system design tool. However, the review of existing models (Chapter 2, Section 2.3.8) highlighted that although some existing models operate on a sub-daily basis for some data sets (such as rainfall) they did not necessarily have the functionality to input sub-daily demand values (Aquacycle, RainCycle, UWOT) or were not public domain or the availability of this function could not be established (MUSIC, PURRS).

Unfortunately the modification of an existing model or the development of a new model to permit incorporation of a sub-daily demand profile was beyond the scope of the work undertaken for this thesis. However, the differences identified in the domestic and non-domestic diurnal demand profiles warrant further research to develop such functionality. Additionally, further work is required to develop a range of demand profiles for different building types, for which RWH may become a serious consideration (schools, warehouses, hotels and so on).

In light of the outlined limitations, an approach had to be determined to assess the impact of differences in domestic and non-domestic demand profiles on RWH system tank design. As the ratio of full to partial flushes had been determined for a non-domestic building (2:1, Section 6.4.7), it was decided to utilise this at a daily timestep as a basis for a design comparison. The ratio of full to partial flushes for a domestic building was established to be 1:4 (That, 2005). The previously utilised RWH system design tool (this Chapter, Section 6.2.1) was used to conduct the design comparison rather than other tools, such as UWOT, as it optimises the tank size estimate and percentage of demand met, whereas UWOT does not.

Using the previously mentioned domestic and non-domestic daily demand ratios, simulations were undertaken for different building occupancies and runoff coefficients (as this was also shown to be a sensitive parameter in the performance assessment section). Daily demands for the given occupancies were calculated using the following daily per capita (l) demand for WC usage:

- Domestic: 1 full flush and 4 partial flushes per day = 6 + (4 x 3) = 18 L;

- Non-domestic: 2 full flushes and 1 partial flush per day = (2 x 6) + 3 = 15 L.

An additional assumption used in the analysis was that the domestic profile would apply for each day of the week (seven days), whereas the non-domestic profile would only apply for five days, due to the building not being occupied at weekends.

The results are summarised in Table 6.19 and appear to show that the influence of variability in the daily demand profile, at a daily timestep, becomes more significant with increased building occupancy. At an occupancy level of 111, the tank sizes and level of demand met are very similar. However, when the occupancy is increased to 300, the impact of the differing profile becomes more pronounced with estimated tank sizes and demand met levels of 9 m^3 and 80% for the non domestic profile and 4 m^3 and 50% for the domestic profile (with a runoff coefficient of 0.9). This may be predominantly attributable to the drop in non-domestic demand at weekends allowing more rainfall to be stored to meet the demand in the following week.

This design comparison hints at the importance of using an appropriate demand profile for the building in which the RWH system is to be situated. However, it does not provide a detailed assessment of the impact of different profiles on the sub-daily operation of the tank, in terms of the YBS and YAS operating regimes. This would only be achievable with a model incorporating a sub-daily demand input function. Therefore this section has highlighted the need for more research in two areas:

- Inclusion of a sub-daily demand profile input function within existing models (such as Mitchell (2005) or Roebuck and Ashley (2007) or the development of a new model);

- Implementation of WC (and other micro-component) usage studies to a range of building types to facilitate development of a portfolio of demand profile types.

Table 6.19 Results of the domestic versus non-domestic system design comparison

Profile Type	Number of Occupants	Daily Demand (m^3)	Tank Size (m^3)	Demand Met (%)	Runoff Coefficient
Non-domestic	111	1.66	2	100	0.9
Non-domestic	111	1.66	3	99	0.6
Domestic	111	1.99	2	84	0.9
Domestic	111	1.99	2	98	0.6
Non-domestic	300	4.5	9	80	0.9
Non-domestic	300	4.5	8	56	0.6
Domestic	300	5.4	4	50	0.9
Domestic	300	5.4	3	33	0.6

6.4.9 Non-Domestic WC Demand Profiling with RWH System Design Comparison: Summary and Key Messages

This section described the development and implementation of a flush counting device, as a proxy for measuring WC water consumption in a non-domestic building. Although the flush counter provided a useful proxy, the use of the data collected was not without limitation, which required a significant amount of post-collection processing. Further development and testing of the device is required to reduce this burden. However, the non-domestic sub-daily demand profile produced using the processed data from the device was corroborated using BMS WC volume of water data. This indicates the data processing procedures undertaken were appropriate and justified.

Analysis of the data identified that due to the presence of waterless urinals in only one out of three male restrooms, the flushing profile of male and female WCs was not significantly different. It was also identified that the sub-daily demand profile and the ratio of full to partial flushes of an office building was distinctly different to a domestic building. Furthermore, a basic design comparison revealed that the inappropriate use of demand profiles can have a significant impact on the design of a RWH system, particularly for high building occupancy rates. However, it was also identified that further work is required in this area to fully understand the implications for RWH system operation at a sub-daily resolution.

The following key messages have been derived from these findings:

(1) A proxy method of quantifying WC demand is available where meters cannot be directly installed on appliances;

(2) The sub-daily demand profile and full to partial flushing ratio for a WC in a non-domestic building are distinctly different to that of a domestic building;

(3) Existing models restrict the representation of demand-side parameters in RWH system designs, necessitating further research in this area.

6.5 Chapter Summary and Key Messages

The purpose of this chapter was to enrich the technical evidence base relating to RWH in the UK. It examined the current methods and tools utilised in the design of RWH systems, evaluated these techniques and compared them to empirical data gathered from a non-domestic building monitoring study. It also outlined the development and implementation of an innovative flush counting device as a proxy for measuring WC demand. Research questions posed at the beginning of the chapter have been answered as follows:

- How do system design methods perform in comparison with empirical data?

Continuous simulations provided the most realistic estimates of RWH system design, suggesting a transition is needed from the simplistic methods currently utilised by system designers. Additionally, awareness and understanding of the importance of the representativeness of the parameters used within design tools need to be raised.

- How does an office-based system perform in terms of water saving efficiency?

The office-based RWH system provided a water saving efficiency of 79% across a winter/spring period. The primary cause of sub-optimal performance was the slow resolution of system faults due to a conflict of interests regarding maintenance activities. This suggests that wider promotion of RWH to SMEs would be appropriate.

- What are the energy consumption and carbon emission implications of systems?

An improved method was developed to quantify RWH system pumping energy requirements. The energy consumption of an office-based system was shown to be a very low proportion of the building's overall energy consumption. This suggests the promotion of RWH in SME environments would be appropriate.

- Are non-domestic demand parameters adequately represented within system designs?

Comparison of a RWH system designed with an empirically derived non-domestic demand profile and the well-established domestic profile indicated that greater emphasis needs to be placed on the importance of demand-side parameters for different building types.

The technical findings of this chapter and the previous chapter are discussed in conjunction with the stakeholder-orientated findings of Chapter 3 and Chapter 4 in the following chapter. The following chapter cross-links and integrates all of the findings and key messages identified throughout the research, in order to fully develop recommendations to achieve objective four and the overall aim of the thesis.

7 CHAPTER 7: INTEGRATING INSIGHTS - BUILDING THE STRATEGIC FRAMEWORK

7.1 Introduction

The previous chapters have analysed and summarised the results from each of the technical and stakeholder data collection activities in isolation. This chapter will re-contextualise the results in terms of the overall thesis aim and integrate and expand on the key messages elucidated in order to outline recommendations. This is fundamental to answer the final research question in relation to the fourth objective of the thesis, which are, respectively:

- What modifications are required within the current RWH system promotion and implementation processes to facilitate greater uptake?

- To develop policy and practice recommendations with the potential to enhance the success of future projects, facilitating greater implementation of RWH in the UK.

This is in turn integral to achieving the overall aim, which is to:

- Develop a strategic framework to support the implementation of rainwater harvesting (RWH) in the UK.

The key messages from the preceding chapters are listed below by chapter for quick reference. In developing the subsequent strategy areas the implementation deficit categories (IDCs) defined in Chapter 4 are used as a starting point, but are adapted to incorporate the key messages of other chapters. Additionally, discussion of the social research theories that are potentially relevant to RWH (Chapter 2) has identified the following key conditions:

- A technology must experience a diffusion of innovation;

- Emphasis must be placed on the relevance of the technology to individual stakeholders;

- Interaction across a range of socio-technical levels must take place.

These conditions are seen as being pre-requites for the transition of a technology, or regime, therefore the derivation of the subsequent strategy areas reflects on their relevance in providing recommendations to support RWH in the UK.

7.2 Summary of Key Messages

7.2.1 Chapter 3:

- Although householder experience with water saving devices is good, the presence of RWH systems in UK developments is not being widely publicised by organisations responsible for the developments;

- Agents responsible for designing new developments should be encouraged to consider the use of communal and combined-use RWH systems, where appropriate;

- A central, independent and reliable source of information needs to be identified if RWH is to be better promoted inline with the direction of recent policy documents;

- Beyond the provision of financial incentives, there is an uncertainty as to the type of factors that would encourage consideration of installation of RWH in households;

- Greater engagement with householders is required to increase knowledge and awareness of maintenance activities and their associated costs (as well as data collection and analysis regarding the costs themselves);

- Innovation in RWH system design, to reduce pumping or simplify maintenance requirements, may be required in order to reduce the cost and commitment required to make systems more attractive to the user;

- The performance of WCs fed by RWH systems should be regularly assessed, to maintain user’s confidence with systems;

- Information gathering activities can form part of the engagement and awareness raising process when conducted in stages and over a suitably long duration.

7.2.2 Chapter 4:

- Visibility of and access to a list of qualified installers is required (such as that due in 2010 under changes to Part G of the Building Regulations);

- Increased training is required for designers/installers to increase implementer confidence and to support the above scheme;

- A central, independent body responsible for coordinating all resources (information, manuals, funding) relating to RWH needs to be established, whether that be a new body or the widening of the remit of an existing body;

- Increased transparency of the ECA application process is required, especially in relation to retrofitting, as well as identification and dissemination of information on other indirect funding/subsidy schemes applicable to RWH.

7.2.3 Chapter 5:

- Awareness needs to be raised regarding the importance of building and roof design and construction in relation to RWH system implementation to maintain good rainwater quality;

- A contaminant flushing effect was statistically inferred after wet periods, for certain parameters. This suggests greater consideration may need to be given to first flush devices for UK RWH systems to reduce the potential flushing effect of rainfall events on WC aesthetics and health risk, though further empirical research is required to examine their efficacy;

- Application of a HIA identified that the health risk posed to occupants flushing WCs with RWH in an office building is minimal and acceptable;

- Activities to raise awareness of this minimal risk need to be undertaken and quantification of results more widely disseminated.

7.2.4 Chapter 6:

- Continuous simulations provided the most realistic estimates of RWH system design, suggesting a transition is needed from the simplistic methods currently utilised by system designers;

- Awareness and understanding of the importance of the representativeness of the parameters used within design tools need to be raised;

- RWH provided a significant proportion of an office WC flushing water demand requirement. This suggests that wider promotion of RWH to SMEs would be appropriate;

- The primary cause of sub-optimal RWH system performance was the slow resolution of system faults due to a conflict of interests between various parties regarding maintenance activities;

- An improved method was developed to quantify RWH system pumping energy requirements. The energy consumption of an office-based system was shown to be a marginal proportion of the building's overall energy consumption;

- Comparison of a RWH system designed with an empirically derived non-domestic demand profile and the well-established domestic profile indicated that greater emphasis needs to be placed on the importance of demand-side parameters for different building types.

7.3 Strategy Areas

In expanding and developing the underpinning themes of the key messages, by integrating the social and technical evidence bases, the following strategic areas naturally arose. Consequently, after re-contextualisation of the previous chapters within the social theory framework, these strategy areas are utilised as the headings for the following sections to focus the proceeding discussion:

- **Product Development;**
- **Capacity Building;**
- **Support Services;**
- **The Strategic Framework.**

In the context of Geels' (2002) multi-level perspective and transition management theory, Figure 4.1 (Chapter 4) provides an overview of the multi-actor network involved in the implementation of a RWH system. Currently in the UK there is an interaction between the meso and micro levels of the RWH network; new policies mention its use (Water Resources Strategy for England and Wales, Flood and Water Management Act) and a small number of change agents are advocating its appropriate use (EA, Chartered Institute for Water and Environmental Management (CIWEM)). De Graaf (2009) identifies such interactions as being indicative of a transformation to a more SWM system. This suggests that the UK RWH sector is in a pre-transitional state or the phase of acceleration; that of being receptive and willing to change, but limited in its ability. In this respect, little progress has been made with regard to the recommendations made by the MTP (Brown, 2007). Other limitations are currently imposed by the inflexibility of conventional systems and concerns over their environmental impact (EA, 2010). Therefore to maintain acceleration and to facilitate a full transition (which may take five to twenty years), rather than failure to transition, strategic measures need to be introduced immediately, to parallel the timescales for climate change adaptation in relation to SWM aspirations.

Reflecting on Geels (2002) case study of the historic shipping transition (Section 2.4.2.2), certain features offer resonance with the growing use of RWH and these are summarised in Table 7.1.

Table 7.1 Comparison between Geel's historic shipping technology transition analysis and the author's analysis of RWH in the UK

Feature of shipping (Geels, 2002)	Feature of RWH
Drivers	Demand reduction, source control
Alternative/expanding/profitable markets	Alternatives to WDS
Dependence on outsiders	Adoption of RWH from market leaders
Diversification/isolated experiments	Alternatives to WDS
Experimentation/design innovations	New RWH products
Innovation as incentive for work	Suppliers identify new market
Laws – protectionism vs. relaxation	Beginning to promote use
Change in hesitant parties	Buy-in from government
Changing established customs	Using non-potable water
New institutions/institutional innovations	RWH associations, trades bodies
New groups/denser networks	SWM advocates
Scepticism represented by rules	Introduction of standards
Liberalisation of rules	Standard as a guide, not mandatory
Management practices change	CfSH
Subsidies	ECA scheme (business only)
Failure to adapt by some trades/services	Lack of buy-in from plumbers
Construction problems	Installation issues
Feedback and communication	Complaints of clients
Circulation of information	Guides, standards
Increased efficiency	Reducing maintenance, increasing financial savings
Huge investment	Private sector
New skills and competencies	Encouraged by Greenplumb
New jobs	Design, installation etc
Wider applications/additional functions	Multiple-use (WCs, laundry)
Benefits to a wider range of groups	Householders, SMEs, schools
Improved facilities	Consistent operation
Decreasing costs	Economies of scale/different products
Faster turnarounds	Implementation time reduces

The analysis presented highlights that there are not only many parallels to be drawn between the two case studies and their operation at the levels of the multi-level perspective, but that the multi-level perspective is also validated by its applicability in elucidating the interactions of the levels. As with certain aspects of Geel's case study, there are certain negative aspects of the author's analysis of RWH; for example, construction problems and failure to adapt by some sectors of the regime. These features have the potential to threaten the success of the current RWH technology transition.

Brown and Keath (2007) assert that failure may be prevented by providing capacities and tools for both the *improvement* of demonstration projects and their *replication*. The transition process also requires the development of a long-term vision and a coalition and mobilisation of stakeholders. De Graaf (2009) identified two key conditions for mainstreaming SWM innovations: (1) enhancing stakeholder receptivity and (2) inclusion in spatial development. Strategy areas accommodating these and the previous assertions are described in the following sub-sections.

7.3.1 Product Development

Socio-technical evidence demonstrating the need for a greater range of RWH products with increased flexibility has been established in several places within this thesis. It relates to two main areas: (1) the physical structure of the system and (2) its ownership.

In relation to the physical structure of the system, it was identified through interviews that SMEs within conservation or heritage status areas and tenanted SMEs who wanted to install RWH were restricted in what they were permitted to do to the outside of a property. Others were restricted due to the amount of outside space available for storage tanks or due to the unsuitability of underlying land type (marshland). Conventional permanent above or below ground RWH systems were inappropriate due to space limitations or restrictions to excavation. In the case of a monitoring programme conducted on an office-based RWH system, it was identified that the payback period of the system was likely to exceed its operational life, primarily due to an over-sized underground storage tank. The literature review also established that the embodied carbon impacts of conventional systems can be in excess of the water saving they provide (when other environmental benefits such as flood alleviation are not included), which currently reduces their advocation by the UK Government due to carbon emission reduction targets (EA, 2010). Further to this, removing the need for systems to pump harvested rainwater would be beneficial at a range of scales, but particularly the at the domestic scale.

Furthermore, in considering such permanent structures in the context of sustainability and climate change, it can be asserted that the adaptability of conventional products is restricted. For example, a conventional RWH system may be fitted to a property in a flood prone area that may subsequently become uninhabitable. The life-cycle impact of the RWH system is increased, due to its reduced operational life and the cost of removing it and reinstalling it elsewhere (or committing it to waste). This scenario would most likely lead to any plans for the inclusion of RWH to be shelved. In such circumstances the availability of a more flexible (less structural) RWH product would have been beneficial. It could have been removed from the property and installed elsewhere (or if it is less structurally intensive, result in less waste).

The increased use of the ‘plastic bag’ storage tank in Japan (Section 2.3.5) and the development of gutter-based systems in Australia (2.3.6) highlight recognition of the need for RWH systems to become more adaptable and flexibly implemented. These systems are also more readily retrofittable; another area of RWH implementation in which the UK needs to increase its expertise if it is to achieve SWM goals. RWH in the UK would benefit from an examination of the products currently being innovated in these countries, rather than the well-established ones that are perhaps less suitable for the UK context. This would permit the pre-transition acceleration phase to be maintained and lead to a greater diffusion of innovation. This reflects back to the work of Geels (2002) that highlights that the technology shift of new niches is a difficult process, involving experimentation, learning, adjustments and reconfigurations, often involving hybridisation.

Regarding ownership of a RWH system, case study evidence identified that conflicts of interest in maintenance provision were responsible for a significant reduction in a system’s operation and performance. Moreover, the use of a survey demonstrated that the willingness of householders to undertake and pay for maintenance activities was low. Sefton (2009) identifies the importance of making SWM techniques accessible and relevant to intended stakeholders. This implies that product development would benefit from greater interaction with prospective system purchasers, even in cases when conventional systems would be logistically suitable. Considering how the functionality of a product fits with the needs of potential customers is a normal part of product development. However, until recently this aspect of RWH system product development may have been side-tracked by an emphasis on system tank sizing techniques. Additionally, current RWH price signals do not encourage behaviour change (web4water, 2009). Product innovation to produce more cost-effective systems, along with the resulting increase in competition, would allow prices to become more acceptable.

Although the recognition for a greater diversity of RWH system products is gradually being made in the UK, as evidenced by the innovative ARC system (Section 2.3.6), the overall incentive for RWH system manufacturers and suppliers to innovate is low as the market for conventional systems is currently growing steadily due to a range of drivers. However, although conventional systems are appropriate in some circumstances, growth in sales does not necessarily result in satisfaction with the system – as this thesis has shown. Current policies and promotional guides (such as those produced by authoritative organisations such as the EA and Envirowise), along with the recent British Standard (BSI, 2009) predominantly describe conventional below/above ground systems without reference to other system types available on the global market. This is primarily due to a comparison of the UK with Germany and Australia, who are ahead of the UK in terms of RWH implementation and are therefore seen as exemplars. Conventional systems dominate in these countries due to the tradition of having basements (Germany) or large lot sizes (Australia). Neither of these contexts is particularly relevant to the UK housing stock.

Consequently, this restricted outlook and the dominance of this system type does nothing to raise the expectation, confidence or interest of stakeholders for which these system types are inappropriate. It therefore does not provide a market demand for innovation. Emphasis needs to be placed on the development of a portfolio of RWH system products, which necessitates further research and development into products suitable for implementation into the UK context. The range of water efficiency products available five to ten years ago was a small proportion of what it is now, but innovation in the sector, along with a parallel receptivity drive with the aim of reducing water demand, has resulted in water efficiency completing the transition from novel to mainstream and expected. Flood management is currently at the stage water efficiency was around five years ago, with the establishment of the National Flood Forum and a call to British Industry for the development of products in relation to flood management being made in early 2010 by the chairman of the EA (Smith, 2010). A similar call needs to be made for RWH to help increase the adaptivity and resilience of water supply infrastructure in the face of climate change.

7.3.1.1 Recommendation

Appropriate organisations (discussed in Section 7.4.1) need to take the lead on recognising, driving and incentivising RWH system product development, to make it technically relevant and applicable to a wider range of site conditions and stakeholder needs. This will facilitate implementation by increasing access to a larger number of stakeholders, as well as easing the burden of RWH not being a ‘fit and forget’ technology.

7.3.2 Capacity Building

Brown and Keath (2007) assert that significant changes in SWM practice can only be facilitated if they are supported at institutional and socio-political levels. At the institutional level the formation of informal networks, negotiating processes and stakeholder coordination are key success factors. Such activities prepare a system for a transition by developing strategies. Countries in which RWH has been successful are shown to have an integrated national programme relating to water, which includes direct reference to and support for RWH projects (Section 2.3.11.4). Additionally, some of these countries are seen to have RWH ‘champions’ who act as high-level change agents.

Although the UK has a selection of water related policies, whether they are integrated is questionable, as is clarity on their position in relation to RWH. Policy tools, such as the Code for Sustainable Homes, promote the use of RWH within the construction sector but provide no guidance or further information regarding the implementation process, as well as not applying to existing housing stock. The onus is still on implementers to undertake a lengthy and resource intensive information gathering process. With respect to Chapters 3 and 4 it has been shown that different stakeholders have differing levels of receptivity (willingness versus ability) and different information requirements.

In terms of the four aspects of the receptivity model (awareness, association, acquisition and application) SMEs were determined to have a good level of awareness and association (they all knew about RWH and its potential relevance to them), but their acquisition and application of it was stalled due to the identified IDCs. For householders the situation was similar, though the level of awareness and association was lower that for SMEs, as some participants were not informed about a system within their own employment building. Again, acquisition and application was stalled for non-users due to factors such as cost and accessibility. For architects all aspects were considered to be well developed, although the application of RWH system design and installation guidance manuals could be improved. However, the small sample of this group restricts the generalisation of findings from this area of the research. Jeffrey and Seaton (2004) assert that external constraints can influence adoption rates for new technologies, even if attitudes and behaviour correspond positively. This has been demonstrated with SMEs and householders, as although they are generally aware of and open to the idea of RWH they are constrained in their ability to act.

The self-efficacy of SMEs also proved to be an important factor in their perception of the implementation process. For example, one SME had been through a difficult building renovation process and decided against undertaking RWH simultaneously to prevent further stress, indicating they did not feel able. In terms of social identification, it was determined that both SMEs and householders did not necessarily demonstrate a bias towards compliance with the actions of their neighbours, relatives and friends or other organisational groupings (environmental groups, different levels of Government). Some even demonstrated a propensity to go *against* these groups, but generally other factors encouraging consideration of RWH were more prominent, such as monetary concerns. Social representations provided further insight into beliefs and practices. Although the majority of householders claimed they practised water conservation and environmental behaviours, the requirement for RWH system maintenance and its potential cost was a discouraging consideration factor. This indicates a degree of willingness, but only to the extent that disruption to 'normal' life is minimised. It has already been ascertained that the receptivity of the stakeholder groups examined is good, therefore there is limited need for further anchoring (relevancy) points. However, these findings demonstrate that there is a greater need for objectifying (increasing the tangibility of) RWH for stakeholders.

A consistent need has been identified for a central, independent and reliable source of information (this aspect will be considered in its own right in the following section, entitled 'Support Services'). The primary focus for UK institutions should be capacity building at intra and inter-organisational levels to develop such a facility. However, recognition will need to be made of the differing needs of stakeholders that will access such a facility. The segmentation approach currently favoured by DEFRA in relation to pro-environmental behaviour change could assist with this. However, it would need to be extended to stakeholder groups other than the general public. For example, the relative importance of the IDCs identified in Chapter 4 was different for different types of SME. Regime-level recognition of this is needed to enhance the receptivity of different stakeholder groups (Jeffrey and Seaton, 2004).

However, this first requires a consensus on RWH by these institutions and recent reports suggest that at the socio-political level there is still some debate as to the sustainability status of RWH (EA, 2010). De Graaf (2009) discovered that urban water managers (in the Dutch context) believed that SWM objectives could be achieved by purely optimising the existing water system. In contrast, in the UK there is widespread recognition that actions are required across a number of levels to facilitate SWM. This is exemplified by the current flurry of activity in relation to water efficiency and flood management. Links are being made at a high level, but recognition of the 'on the ground' issues restricting widespread SWM, such as low user confidence due to a lack of expertise in RWH installations, is low. The system may still be too top-down, rather than bottom-up. Further examination into the receptivity of UK construction practitioners, water managers and policy makers to RWH using the theoretical and methodological approach used in the present study is suggested in Section 8.3 (suggestions for further research).

Despite the impasse regarding the status of RWH, steps are being taken to form relationships and develop resources with respect to wider SWM and spatial planning agendas. A guide is currently under development in a partnership between CIWEM, DCLG and DEFRA, with the assistance of the consultancy Jacobs (Ellis, 2010). The guide will 'signpost' all water-relevant policy plans (Planning Policy Statements (PPs), Regional Spatial Strategies, (RSSs) Local Development Frameworks (LDFs), Area Action Plans (AAPs) and so on) and critical SWM tools (River Basin Management Plans (RBMPs), Surface Water Management Plans (SWMPs), Flood Risk Management

Plans (FRMPs) and so on). The primary aim of the document is to integrate the water and spatial planning sectors to embed water in sustainable development agendas. However, it will only be effective if relevant stakeholders are engaged, its relevance emphasised via appropriate means (training, workshops etc) and lessons learnt disseminated. By embedding water in planning, by considering RWH (and other SWM measures) as responses within SWMPs to provide source control, help alleviate flooding and supplement the WDS, such techniques will become more familiar to LAs and planning departments. This will drive capacity building activities within these organisations, including the extension of partnership working between planners and water professionals. This increase in capacity will in turn reduce the perception of planning departments as being obstructive to RWH, as exposed in Chapter 4.

Geels (2002) asserts that actors will only support incremental change if it does not threaten their position in the status quo. At a practical/operational level RWH system manufacturers, suppliers and installers and their roles must be supported to encompass the assimilation of new knowledge and skills. Additionally WSPs must be supported to accept such techniques, rather than seeing them as competing with their income streams. This study has identified a need to increase the knowledge and expertise of system implementers to ensure the success of projects and instil user confidence. The proposed CIHPE qualified installers list will go some way to building capacity for these actors, if it is implemented and administered suitably. This is however only one step and anticipation of how it will be received by the installation community will need careful consideration. Adequate provision of training schemes and workshops (i.e. support services) in relation to this initiative will be crucial in building capacity with system implementers. This scheme could also be extended to include RWH system designers and training provided on the tools freely available to assist in designs and feasibility assessments.

The CIHPE scheme will not, however, build capacity within the potential RWH system user community and therefore other measures are required for these stakeholders. Demonstration projects have been highlighted as a way to develop knowledge and experience of new technologies (Sharp, 2006). Although their direct contribution to the transition is low (as the technology is unlikely to be perfected pre-transition), they support it indirectly through increasing receptivity to concepts outside the accepted norm and demonstrating their relevance to the community (Sefton, 2009). Chapter 4 established the need for RWH demonstration projects with SMEs. One SME called for the creation of a 'buddy database'; a list of businesses with RWH that a similar sized business wanting to install RWH could contact/visit to see how the system operates and talk to them about the implementation process. This would build capacity and confidence within the SME community who have been identified as being cynical about adapting to address environmental issues and displaying 'green fatigue'. This is partly due to the perceived costs (including non-financial costs such as time/stress) involved outweighing the benefits (Tenon Forum, 2008). Envirowise is beginning to assist in this respect, for example it released a leaflet on RWH in 2009. However, this only promotes its use; it does not actually enable SMEs in a tangible way and does not build capacity. It again assumes that once information is in the domain of the SMEs, they will act on it. Chapter 3 shows that this is not the case, due to the lack of other support mechanisms and that there is much more to the implementation process than purely information provision.

The requirement for access to demonstration projects was not as well established for householders (Chapter 3). This may be due to a reduced receptivity within this stakeholder group, resulting from the perceived expense and commitment inherent in owning a conventional system. It was also identified that some office occupants did not know they were using a WC supplied by a RWH system. In order to build awareness of the use of systems to facilitate receptivity, such systems need to be more widely publicised – this will help them lose their 'novelty' value. Chapter 3 also identified concerns regarding the quality of harvested rainwater used for flushing WCs. However, Chapter 5 quantitatively determined that the health risk posed was minimal and within the level deemed (politically) to be acceptable. Greater application of a HIA approach when designing RWH could reassure end-users of the low risk posed by RWH, thus facilitating their receptivity to it. Of course facilitating application of HIAs (and other design/feasibility assessment/decision support tools) could require further capacity building with relevant stakeholders and additional support services to disseminate the knowledge obtained.

7.3.2.1 Recommendation

Appropriate organisations (discussed in Section 7.4.1) need to develop stakeholder-specific interventions that address their needs in relation to the implementation of

RWH. This will enhance their receptivity to RWH in advance of appropriate technical innovation been enabled.

7.3.3 Support Services

Over the last five years certain facets of sustainable construction and development have received institutional commitment and support. For example, water efficiency and micro-energy generation programmes have both received structured commitment and support in the form of publicly funded pilot schemes, grant programmes and initiatives on scaling-up the results (the theme of Waterwise's 2010 water efficiency conference). The development and implementation of such schemes and initiatives demonstrates institutional commitment. Brown and Keath (2007) emphasise that it is important to foster strong levels of interaction between niches and the regime to facilitate receptivity. The above schemes signal to stakeholder communities that the measures are considered robust and warrant assistance. In relation to RWH such support system signals have been identified in countries where RWH is more widespread. Developments in other areas are perhaps required before RWH is considered robust enough to warrant full institutional support (i.e. beyond the level of simply promoting its use). However, it is likely to be a 'catch 22' (no win or a double bind) situation and therefore consideration should perhaps be given to committing to provide an extended range of support services to demonstrate greater commitment to RWH.

For example, the previously mentioned water and planning guide represents a potential model for a similar guide on RWH. Usually policy or technology promotion campaigns advocate the gathering and dissemination of large amounts of information to stakeholders. For RWH such information already exists. There is currently a vast range of documents relating to RWH in the UK (as highlighted in Chapter 3, Section 3.4.2.3). However, visibility of and access to these documents is limited. The questionnaire undertaken with architects and construction practitioners in Chapter 3 highlights that although a wide range of documents exist, their use is limited. This poses a direct threat to the success of implementation by undermining the level of expertise of the implementer, which consequently undermines user confidence (highlighted in Chapter 4). A freely available 'signposting' document could be produced which would allow stakeholders interested in RWH easy access to an overview of information and other relevant documents. Such a document could be signposted in revisions to relevant policy and guidance documents (CfSHs, BSI, Water and Planning Guide).

The provision of the previously mentioned central information source could also facilitate the dissemination of such documents to relevant stakeholders, as well as being an easily promotable support service. Having a central body, which could provide a 'vetting' function for information, could improve the credibility, integrity and consistency of information being distributed. These attributes were highlighted in Section 4 as being crucial for increasing the receptivity of stakeholders to new technologies.

In addition to issues of visibility and access, document costs were also suggested as a potential deterrent to use. Indirect financial support could be granted to enhance their visibility and accessibility. Further to this, if the Government would prefer not to give direct financial incentives, such as the grants and subsidies seen in other countries, indirect financial support would be a suitable compromise. For example, providing grants or loans for feasibility assessments would provide non-product based non-structural support to stakeholders interested in implementing RWH at a range of scales. However, such assessments would need to be conducted by qualified individuals with a full knowledge of RWH systems, otherwise the suitability of RWH may be misjudged (as identified in Chapter 4).

Previous research (Gould, 1999; Parsons *et al*., 2010) has established that developers are only willing to undertake additional requirements for sustainable development if they do not interfere with their construction schedules or overheads. Although the ECA scheme would assist with this, its accessibility and administration has been highlighted as inadequate through this research and a lack of financial support has been highlighted in other studies (Brown, 2007). This has the potential to result in the RWH system being value-engineered out of projects. This was observed in stakeholder-scoping interviews in relation to several school projects, which are not described in this thesis as resource limitations meant this stakeholder group could not be fully included in those investigated. The drive to seek the lowest cost and most easily-implementable development is also highlighted by De Graaf (2009) as an inhibitor to transitioning. Improving the range of and accessibility to relevant indirect financial services would be beneficial to a number of stakeholers. White's DETA model (2009) highlighted the importance of financial tools for receptivity at the household level. However, in the UK context it may be more timely to implement these when the portfolio of products available on the UK market has been suitably augmented.

It has been established that there are significant links between water, energy and carbon emissions. In 2008 the Carbon Trust announced a £31 million loan pot available to SMEs for energy efficiency measures, but this was not linked with water. Such supporting financial incentives could be extended to cover RWH and applied to other stakeholders to bridge the gap in financial support identified in this thesis. The Energy Saving Trust recently extended its remit to include water, in partnership with Waterwise (EST, 2009). The partnership's 'Life + Water and Energy' project provides funding for advisors to deliver water and energy advice to householders in pilot areas (Cardiff, Edinburgh and London – approximately five million customers). Although it is unlikely RWH will be included in detail in this initiative, it may provide a model for future reference.

Support for RWH also needs to be engendered in the overall water management process itself. Metered customers benefit most from having RWH as they receive the direct benefits of paying for the lower volume of mains water used and subsequently a reduced sewerage charge. However, those not on meters can benefit in some water company areas, which have revised surface water drainage charging arrangements. However, few stakeholders are aware of this and the process of calculating the discount varies. Standardisation of this process and increasing its visibility would potentially broaden the appeal of RWH to certain stakeholders. Additionally, the EA's call for universal domestic metering would increase the attractiveness of RWH in areas where water charges are relatively high. However, this would need to be complemented with access to suitable cost-effective and appropriately designed RWH systems.

7.3.3.1 Recommendation

Appropriate organisations (discussed in Section 7.4.1) need to develop services to support technical development and capacity building activities. This will demonstrate commitment and increase stakeholder confidence in implementing RWH.

7.4 The Strategic Framework

The discussion in this chapter has demonstrated that a diverse range of social research frameworks are relevant to the status and transition potential of RWH in the UK. This highlights the relevance of social science in contributing to SWM implementation, which is not always recognised at the institutional level in the UK. Consideration of these frameworks, in combination with socio-technical evidence bases that fill current knowledge gaps, has resulted in strategic recommendations with the potential to support the implementation of and facilitate the transition of RWH from novel to mainstream. This chapter has provided an answer to the final research question along with recommendations to complete the fourth objective of the research. This results in the achievement of the overall aim of the thesis; to develop a strategic framework to support the implementation of rainwater harvesting (RWH) in the UK. The subsequent strategic relationship between the RWH vision (suggested as being an increase in implementation and denoted with a 'V'), its actors, the strategy areas and their level of operation is illustrated in Figure 7.1 in the form of a Venn diagram.

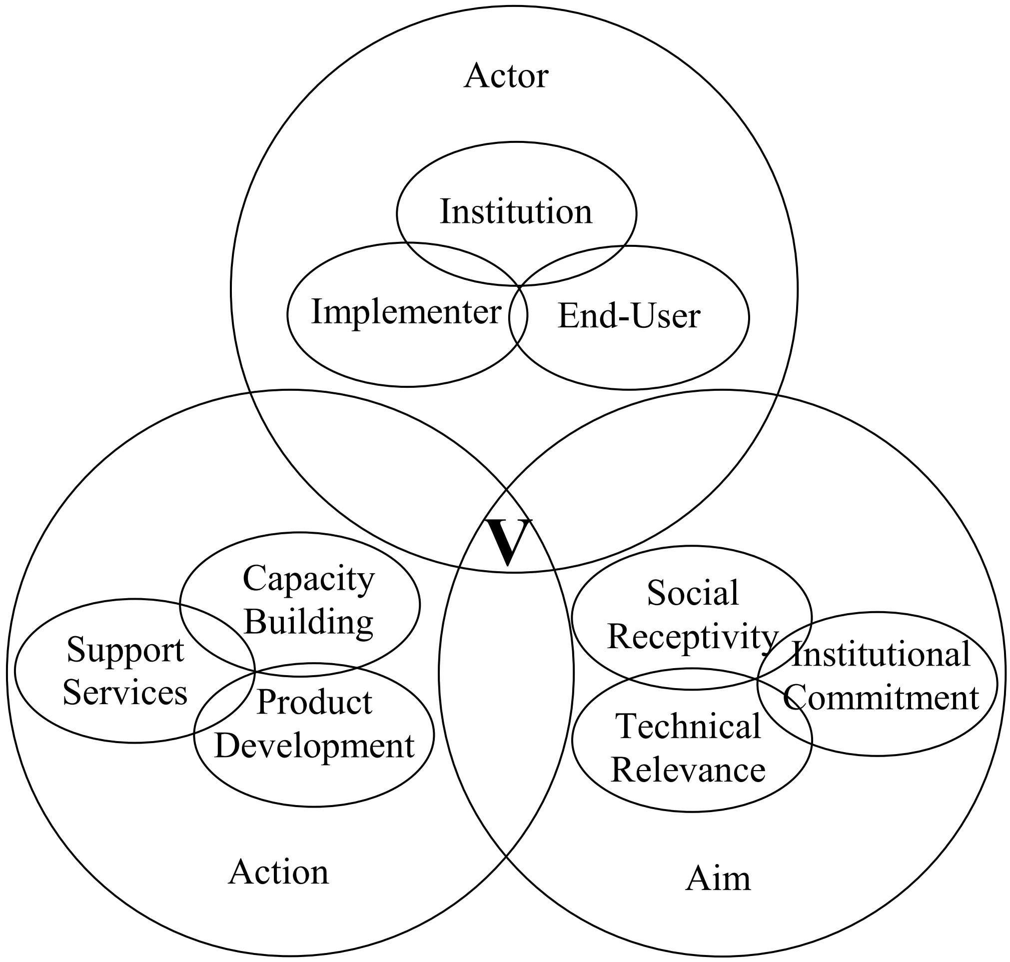


Figure 7.1 The Strategic Framework for RWH

7.4.1 Implementing the Framework – Guidance for Stakeholders

In order for the maximum benefit to be achieved from deriving the framework, it is important to outline how it may be applied and who can apply it. Therefore this section provides a brief overview of these aspects, by giving examples of stakeholders and the actions they could take to help facilitate (where appropriate) the successful implementation of RWH.

Throughout this thesis a range of stakeholders and organisations have been identified and in the previous section action areas based on the key findings resulted in recommendations directed towards 'appropriate organisations'. Although it is not for this thesis to prescribe who these organisations may be, it is important to highlight the types of organisation to whom the framework may be of most relevance. In the context of the thesis, the organisations fit into three main categories, which are summarised in Table 7.2. Examples of organisations for the UK are also given within the table, along with details of specific actions that could be taken, derived from the strategic framework recommendations (these are italicised under the 'Action-Aim' column heading). Additionally, the actors outlined in the framework are included across the examples in a range of ways, to demonstrate how they interact with the actions and aims.

The organisations and actions outlined in the table are not intended to be comprehensive or absolute, but merely an indicator of how the strategic framework recommendations can be interpreted in relation to its actors, actions, aims and the overall 'vision' for RWH. Primarily the recommendations are directed at policy makers, as it is at this level that the majority of decisions are made that affect the focus and dissemination of product development, capacity building and support service activities, which heavily influence the pathways actors in other parts of a regime or transition take.

For example, at the policy making level, it may be necessary for the *institution* of DEFRA *(actor)* to undertake a review of RWH research (*action*) to identify which *product development, capacity building* and *support service* activities *(actions)* it could develop or advocate in order to demonstrate *commitment (aim)* to *building capacity* and increasing *technical relevance (aim)* for *implementers (actor)* to enhance the *receptivity (aim)* of *end-users (actor)* to RWH.

Table 7.2 Example Actors and Actions for Implementing the Strategic Framework

	Example Actor	Context	Action – Aim
1. Policy Informer	Research Councils (e.g. EPSRC)	Undertaking cutting edge research through Universities and Institutions	Undertake/fund research into *product development* to increase *technical relevance* of RWH systems to *end-users* and increase institutional confidence
	Consumer Council for Water (CCW)	The voice of UK water consumers	Inform consumers (*end users*) of potential alternatives to the centralised WDS to *build capacity* and increase *social receptivity*
	UK Water Industry Research (UKWIR)	Research for UK water operators	Investigate the impact of RWH on WDS/sewers to enhance *technical relevance/institutional commitment*
	Drinking Water Inspectorate	Independent research on water supply safety	Undertake and disseminate information regarding RWH health risks to all *actors* to address *social receptivity*
2. Policy Maker	EA	Water resources management/environmental protection	Provide/signpost a central source of guidance/support to *build capacity* and *social receptivity* with *implementers* and *end-users*
	DEFRA	Environment/Water related policy	Use FPEB/segmentation to identify a greater range of *support services* for *implementers* and *end-users* to support all *actions*
	DCLG	Planning policy	Better signpost *support services* in PPSs
	DECC	Climate change adaption policy	Extend remit to cover the water-energy nexus to increase *institutional commitment*
	OFWAT	Water pricing policy	Incentivise WSPs to consider alternatives to increase *institutional commitment*
3. Policy Implementer	Local Authorities	Building control and the planning system	Signpost the EA/Greenplumb *support services* through the existing www.direct.gov.uk 'find a plumber' facility to enable *implementers*
	Water service providers	Planning and investing in infrastructure	Extend water efficiency information to cover RWH to increase *end user social receptivity*
	Water Managers	Consultancies undertaking SWMPs, FRMPs etc	Increase consideration of SWM options to enhance *social receptivity/capacity building*
	Architects	Designing new buildings and developments	Increase awareness of tools/data for designing RWH systems to enhance *technical relevance*
	Developers	Constructing new buildings and developments	Campaign for greater *product development* and *support services* to increase *technical relevance* and *build capacity* for *implementers*
	RWH System Suppliers	Product designers/manufacturers	Undertake *product development* activities to increase *technical relevance* to *end-users*

8 CHAPTER 8: CONCLUSION, IMPACT PLAN AND FURTHER RESEARCH

8.1 Conclusion

Drivers including increasing water demand and risk of flooding have led to the beginning of a shift away from conventional water and urban drainage management practices, towards SWM techniques in the UK. This is evidenced by the recent introduction of the Flood and Water Management Act, which aims to enable the SUDS adoption and maintenance process, for example.

However, it has been identified that for other SWM techniques, such as RWH, there remain a number of barriers and gaps in knowledge, which have the potential to prevent them becoming mainstream SWM measures. Direct barriers include unfamiliarity with the unconventional; capital outlay; installation, operation and maintenance issues; a shortage of expertise and health and safety fears. Indirect barriers include a lack of non-domestic demand data with which to appropriately design non-domestic RWH systems, in order to avoid excessive capital and installation costs. These barriers highlight that most *social* concerns focus on *financial* and *technical* aspects of a RWH system.

Examination of the situation of RWH in countries regarded as 'market leaders' identified that RWH in the UK is beginning to demonstrate similar features, although there are notable gaps. In particular, this includes a lack of public awareness of RWH and engaging with and enabling stakeholders to consider implementing RWH. These activities would undoubtedly go some way to address the previously mentioned direct and indirect barriers. Current UK policy and support mechanisms only go so far in enabling stakeholders to successfully implement RWH.

This research therefore sought to understand the socio-technical interface of RWH in the UK, by deriving and applying a social theory-based framework to engineering-oriented knowledge gaps, such as system performance and water quality. This understanding was required in order to subsequently develop a strategic framework, based on empirical data, to support the transition of RWH from novel to mainstream. The research has established that the socio-technical aspects of RWH systems are intimately interwoven and require an interdisciplinary approach to their investigation. Social and technical evidence gathering resulted in a number of key messages.

Interviews with SMEs and a survey of householders revealed that despite a willingness to consider utilisation of RWH, it is still regarded as aspirational and they are not able to easily undertake its implementation. In relation to SMEs, 'implementation deficit categories' were developed and highlighted 5 areas of concern, which are:

- Expertise and Advice;
- Guidance and Support;
- Visibility and Access;
- Confidence and Communication;
- Finance and Consultation.

For householders the primary concerns were maintenance commitments and uncertainties regarding the risk in relation to using RWH. Participants associated a higher risk with end uses that became increasingly personal. Water quality results and their inclusion within a QMRA/HIA showed that the risk to health posed by flushing a WC with RWH was inline with the recognised screening level and less than the risk posed by being struck by lightning. These two findings indicate that the low risk posed by utilising RWH for WC needs to be more widely publicised, to overcome public perceptions and concerns. Additionally, for householders it was identified that financial support was the most prominent issue restricting their consideration of implementing RWH.

Integration of the social and technical evidence bases using triangulation, elucidated strategy areas on which to build the strategic framework, as well as permitting examination of the validity of the social theory framework. Triangulation of the key messages and findings confirmed that the concepts of technology transition, multi-level perspective, receptivity, DI, EM, receptivity, self-efficacy, social identification and social representations were all relevant to socio-technical aspects of RWH, at differing levels and to differing degrees. For example, weaknesses in one approach were counterbalanced by the inclusion of another approach (self-efficacy and DI, respectively). Furthermore, the findings of the present study concur with previous studies, where the theories have been applied individually (or in combination, but not the full combination utilised here) to RWH or SWM issues.

On the basis of the triangulation activities and the strategy areas defined, a full strategic framework (the overall aim of the research) was developed. The comprehensive strategy considered the socio-technical aspects associated with RWH systems, in terms of the system components and their function, their installation and operation, as well as the relationship of stakeholders with their implementation and utilisation. Strategy areas have been identified that could enhance the receptivity of stakeholders currently outside the feasible implementation process. This involves modification of the UK RWH field to incorporate the values, knowledge and capacities of new potential recipients.

The strategy is the culmination of an extensive review of previous research and empirical evidence collection and outlines recommendations for action in the form of the key messages summarised at the beginning of this chapter. The strategy action areas and the aims they support are defined as:

- Product Development – building technical relevance;

- Capacity Building – building social and institutional receptivity;

- Support Services – demonstrating institutional commitment.

Figure 7.1 (previous chapter, Section 7.4) summarises the entire strategic framework, including outlining the strategy *aim* relevant to each stakeholder group (*actor*) and the appropriate *action* that needs to be undertaken.

The research has demonstrated that the application of social theory to engineering techniques has provided a comprehensive understanding of the barriers to RWH in the UK, which may not have been achieved, had the research only assumed one perspective. This highlights that a transition is needed from perceiving RWH systems and indeed SWM as a whole, in technical isolation; it needs to be regarded as a socio-technical entity. Only when this perspective is fully adopted, will implementation be improved, stakeholder confidence increased and the probability of RWH transitioning from novel to mainstream enhanced.

8.2 Impact plan

This thesis has identified both top-down and bottom-up actions that need to be undertaken to maintain the acceleration of RWH in the novel-mainstream transition process. Disseminating these actions is key to supporting the success of RWH in the UK. Often academic research is only disseminated at the academic level. This is useful for disciplinary paradigm-shifts and cutting-edge thinking, but for tangible societal impacts to be felt, wider dissemination is required. In response to this, engagement with relevant UK RWH stakeholders will be undertaken at a range of levels:

- Policy Informers
- Policy Makers
- Policy Implementers

The UKRHA (mainly tradespeople) campaigned for the recent BS, as well as a training programme to ensure installation standards. This thesis reinforces these needs from an unbiased viewpoint, as well as establishing other needs such as product innovation. Dissemination of findings to members of UKRHA provides potential to increase momentum in this area. Activities have commenced, with the author being asked to present at the 'Sustainability Live!' event at the Birmingham NEC in April 2010.

To facilitate change at the institutional level it is proposed to disseminate this thesis (via presentations or reports) to a range of institutional-level actors, such as Envirowise and those involved with DEFRA's pro-environmental behaviours framework. This will be complemented with the submission of papers to a selection of appropriate journals (this activity has commenced and publications to date are located in Appendix A). This forms part of the transition management process, as it links the formal political decision making process with academic research. Not only will this assist in building capacity, but also in facilitating recognition of RWH as a socio-technical system for which social receptivity and technical relevance need to be addressed in parallel.

With respect to other interested parties, the results of the water quality study have already been disseminated to the water efficiency and public health departments of South West Water. It is hoped this will raise awareness of the low risk posed to health by not only identifying causes of contamination, but by quantifying and bench marking them using the QMRA/HIA approach.

8.3 Further Research

Several areas of the research could be expanded upon, these are as follows.

8.3.1 Product Innovation

Although some innovative systems are currently being developed, greater exploration of other possible system configurations is required to ensure systems are both adaptable, flexible and affordable to allow implementation in a range of building types. Further study into the applicability of first flush devices to the UK context and examination of maintenance costs should also be undertaken.

8.3.2 Undertake a Charrette

Further research could cover the inclusion of other stakeholder groups such as planners, suppliers and developers. Additionally, more detailed research is required to fully understand the motivations and requirements of householders. A stakeholder-wide Charrette on RWH would provide an opportunity to fill these knowledge gaps, as well as simultaneously building capacity.

8.3.3 3D Visualisation of 'RWH Buddies'

Within the research undertaken for this thesis, it was identified that SMEs would like the opportunity to interact with a 'buddy' RWH system or demonstration sites. In addition there was a preference for not travelling too far, as well as seeing historic operational data for the system. Use of empirical data collected from monitoring activities, combined with 3D visualisation tools would allow this to be done in a novel and interesting way facilitating capacity building between a range of stakeholders.

8.3.4 Tank Sediment Quality study

This thesis outlined the quality of harvested rainwater at the point of use. However, it did not encompass coverage of the quality of sediments in the main storage tank. No research in this area could be identified for the UK context. It would therefore be useful to undertake such studies at a range of UK sites to ascertain the potential impact of sediment disposal on recipient bodies, as RWH becomes increasingly implemented.

8.3.5 Technical Impacts on Demand Behaviour

The flush counter study undertaken in this thesis could be repeated with labelling installed on the WCs flushing buttons to observe behaviour change. Some WCs have large buttons for full flushes and small buttons for partial flushes; whereas for other products it is the opposite. The impact of this on user behaviour could be assessed for a number of building types using the flush counter developed.

8.3.6 Demand Profiling

It was beyond the scope of the present study to implement the demand profiles developed within a decision support tool or computer based model, for example the UWOT tool. Further research would allow this to be undertaken to permit the investigation of sub-daily profiles on adopting a range of alternative water resources, including a sensitivity analysis of time-step. Further research is also required in this area to develop a portfolio of demand profiles for different building types (schools, supermarkets, vehicle washing facilities) to facilitate system designs and reduce costs.

8.3.7 Micro-renewable Energy Generation

An idea that has received a lot of attention on the amateur invention circuit is that of converting the potential energy of water falling through downpipes to electricity. It is possible that the amount of energy generated is extremely small from a domestic building – perhaps enough to power a 40 watt light bulb for 5 hours. However, within a large office building the energy could be enough to cover the electricity required by the pump. This would reduce the carbon emission impact of pumped RWH systems (where pumps cannot be fully eliminated). Simple small hydroelectric generators exist and could be readily installed in the office building monitored within the present study for empirical assessment. Other renewable micro-generation techniques, such as solar could be used (or a combination), but these generally require a larger amount of infrastructure for installation increasing both capital and carbon impacts.

8.3.8 Apply the ESTEEM/SOCROBUST Methodology

A recent (2008) European project (Raven *et al.*, 2009), 'Create Acceptance', developed a tool to measure and promote social acceptance of technologies for renewable energy sources and rational use of energy. The ESTEEM tool ('Engage stakeholders through a systematic toolbox to manage new energy projects') assists new energy project managers in improving the societal acceptance of their project by stimulating the participation of stakeholders. The project recognised that in order to be successful, energy projects need to fit into various social contexts. The project used the SOCROBUST ('socially robust') methodology to help managers to better understand the history and present positioning of their project, in order to determine appropriate next steps to promote and enhance its social viability. The methodology supports managers in:

- Identifying and describing societal dimension of their projects;
- Eliciting the key societal changes required;
- Defining the limits of the actions taken to trigger such changes;
- Assessing the associated risk/likelihood of achieving these changes.

To the best of the author's knowledge, the ESTEEEM and SOCROBUST tools have only been applied in the field of renewable energy; they have not yet been applied to the field of SWM. This is likely due to the fact that social science approaches have only recently started being applied to the SWM context, as highlighted in this thesis. Some of the steps of the SOCROBUST methodology echo the approach taken and framework developed in this thesis. However, due to the timing of the discovery of SOCROBUST within the present study, it was not possible to formally apply the methodology to examine its validity for RWH or indeed SWM. Further work, building on the framework developed for this thesis, could apply the SOCROBUST methodology to extend the analysis of the innovation transition process for RWH/SWM in the UK. This comparison would perhaps formally validate the approach developed in this thesis, resulting in reinforcement of the strategy areas determined, thus producing a robust framework for policy makers to follow when considering measures to support the implementation of RWH/SWM in the UK.

REFERENCES

AAPOR (2006) Response Rates - An Overview. http://www.aapor.org/Response_Rates_An_Overview.htm Accessed 27 October 2009

AHMED, W., HUYGENS, F., GOONETILLEKE, A. & GARDNER, T. (2008) Real-Time PCR Detection of Pathogenic Microorganisms in Roof-Harvested Rainwater of Southeast Queensland, Australia. *Applied and Environmental Microbiology*, 74 (17), 5490-5496.

ALBRECHTSEN, H. J. (2002) Microbial investigations of rainwater and graywater collected for toilet flushing. *Water Science and Technology*, 46, 311–316.

AMIN, M. T. & HAN, M. (2009) Roof-harvested rainwater for potable purposes: application of solar collector disinfection (SOCO-DIS). *Water Research*, 43 (20), 5225-5235.

APHA (2000) Standard Methods for the Examination of Water and Wastewater. APHA, Washington.

APPAN, A. (2000) A dual-mode system for harnessing roofwater for non-potable uses. *Urban Water*, 1 (4), 317-321.

ARTHUR, S. & WRIGHT, G. B. (2005) Recent and Future Advances in Roof Drainage Design and Performance. *Building Services Engineering Research and Technology.*, 26 (4), 337-348.

ARUP (2005) Comprehensive Environmental Performance Assessment Scheme for Buildings: Pre-Design Stage., ARUP Buildings Department; http://www.bd.gov.hk/english/documents/code/cepas/PredesignStageE.pdf Accessed 08 April 2009

ASHLEY, R. M., BALMFORTH, D. J., SAUL, A. J. & BLANKSBY, J. D. (2005) Flooding in the future - predicting climate change, risks and responses in urban areas. *Water Science and Technology*, 52 (5), 265-273.

ASHLEY, R. M., BLACKWOOD, D., BUTLER, D., DAVIES, J., JOWITT, P. & SMITH, H. (2003) Sustainable decision making for the UK water industry. *Proceedings of the Institution of Civil Engineers Engineering Sustainability*, I56, ES1, 41-49.

ASHLEY, R. M., BLACKWOOD, D., BUTLER, D., JOWITT, P., DAVIES, J., SMITH, H., GILMOUR, D. & OLTEAN-DUMBRAVA, C. (2008) Making Asset Investment Decisions for Wastewater Systems That Include Sustainability. ASCE *Journal of Environmental Engineering*, 134 (3), 200-209.

ASTEBØL, S. O., HVITVED-JACOBSEN, T. & SIMONSEN, Ø. (2004) Sustainable stormwater management at Fornebu - from an airport to an industrial and residential area of the city of Oslo, Norway. *Science of the Total Environment*, 334-335, 239-249.

BAKER MACKENZIE LLP (2008) Addressing Water Scarcity Through Recycling and Reuse: A Menu for Policymakers. TP1161EN. http://www.gewater.com/who_we_are/press_center/whitepaper/2008/reuse_menu/download.jsp Accessed 12 April 2009

BARR, S. (2002) Household Waste in Social Perspective: Values, Attitudes, Situation and Behaviour. Ashgate Studies in Environmental Policy and Practice, Aldershot.

BARR, S. (2009) Discussion on cooperation rates and interview numbers. Personal Communication, Email. University of Exeter. 08 May 2009.

BARR, S. & GILG, A. W. (2007) A conceptual framework for understanding and analyzing attitudes towards environmental behaviour. *Geographical Annual: Journal Compilation of the Swedish Society for Anthropology and Geography*, 89 B (4), 361-379.

BBC (2009) UK in recession as economy slides. http://news.bbc.co.uk/1/hi/business/7846266.stm Accessed 28 February 2009

BECKER, M. & RAASCH, U. (2001) Sustainable rainwater management in the Emscher river catchment area. Proceedings of the 2nd International Conference on Interactions between Sewers, Treatment Plants and Receiving Waters in Urban Areas (Interurba II). Lisbon, Portugal, 19-22 February.

BIRKS, R., COLBOURNE, J., HILLS, S. & HOBSON, R. (2004) Microbiological water quality in a large in-building, water recycling facility. *Water Science and Technology*, 50 (2), 165-172.

BIRKS, R., HILLS, S., GRANT, E. & VERRECHT, B. (2008) Community scale non-potable reuse in London using an MBR. *Water Practice and Technology*, 3 (2), http://www.iwaponline.com/wpt/003/wpt0030047.htm Accessed 22 December 2008

BISWAS, A. K. (2004) Integrated Water Resources Management: A Reassessment. *Water International*, 29 (2), 248-256.

BMRB (2006) BMRB Telephone Omnibus Survey - Save the Rain. Prepared for IAS Smarts by BMRB Omnibus (46104439-om630).

BPS (2006) Code of Ethics and Conduct. http://www.bps.org.uk/document-download-area/document-download$.cfm?file_uuid=E6917759-9799-434A-F313-9C35698E1864&ext=pdf Accessed 12 January 2008

BREEAM (2007) BREEAM: BRE Environmental Assessment Method. http://www.breeam.org/index.jsp Accessed 18 October 2007

BREWER, D., BROWN, R. & STANFIELD, G. (2001) Rainwater and Greywater in Buildings: project report and case studies. TN 7/2001. DETR and BSRIA, London. ISBN 0860225771.

BROWN, R. (2007) Rainwater and Grey Water: Report of the consultation workshop. BSRIA Ltd for the Market Transformation Programme. www.mtprog.com

BROWN, R. (2008) Social and Institutional Requirements. IN FLETCHER, T. & DELECTIC, A. (Eds.) Data Requirements for Integrated Urban Water Management. Taylor and Francis, London.

BROWN, R. & KEATH, N. (2007) Turning the super-tanker: Drawing on Social Theory to Enable the Transition to Sustainable Urban Water Management. 13th International Rainwater Catchment Systems Conference. Sydney, Australia.

BROWN, R. R., SHARP, L. & ASHLEY, R. M. (2006) Implementation impediments to institutionalising the practice of sustainable urban water management. *Water Science and Technology*, 54 (6), 415-422.

BSI (2009) BS 8515:2009 - Rainwater harvesting systems - Code of practice. BSI, London.

BULKELEY, H. (2006) A Changing Climate for Spatial Planning. *Planning Theory & Practice*, 7 (2), 203-214.

BUTLER, D. (1991) The Influence of Dwelling Occupancy and Day of the Week on Domestic Appliance Wastewater Discharges. *Building and Environment*, 28 (1), 73-79.

BUTLER, D. & DAVIES, J. (2004) Urban Drainage. Taylor and Francis, London.

BUTLER, D. & WARD, S. (2009) Report on approaches to UWWTD compliance in relation to CSOs in major cities across the EU. Internal Report, Exeter Enterprise, University of Exeter.

CDIAC (2010) Frequently Asked Questions. http://cdiac.ornl.gov/pns/faq.html. Accessed 15 January 2010

CHAPMAN, H., CARTWRIGHT, T. & TRIPODI, N. (2008) Guidance Manual for the Design and Installation of Urban Roofwater Harvesting Systems in Australia (Edition 1), Research Report 39. Cooperative Research Centre for Water Quality and Treatment. ISBN 18766 16644
http://www.waterquality.crc.org.au/publications/report39_rainwater_tank_manual.pdf
Accessed 15 October 2008

CHAPMAN, H., HUSTON, R., GARDNER, T., CHAN, A. & SHAW, G. (2006) Chemical water quality and health risk assessment of urban rainwater tanks. 7th International Conference on Urban Drainage Modelling and 4th International Conference on Water Sensitive Urban Design. Melbourne, Australia.

CHAUDHURI, S., CLAUER, N. & SEMHI, B. (2007) Plant decay as a major control of river dissolved potassium: A first estimate. *Chemical Geology*, 243, 178-190.

CHENG, C. L., LIAO, M. C. & LEE, M. C. (2006) A quantitative evaluation method for rainwater use guideline. *Building Services Engineering Research and Technology*, 27 (3), 209-218.

CHILTON, J. C., MAIDMENT, G. G., MARRIOTT, D., FRANCIS, A. & TOBIAS, G. (1999) Case study of a rainwater recovery system in a commercial building with a large roof. *Urban Water*, 1 (4), 345-354.

CHIU, Y. R., LIAW, C. H. & TSAI, Y. L. (2009) Harvesting Rainwater, an Innovative Approach to Easing Urban Water-Energy Dilema. 14th International Conference on Rainwater Catchment Systems. Kuala Lumpur.

CHU, S. C. & FOK, Y.-S. (1991) Multiobjective Rain Water Cistern Systems. Proceedings of the 5th International Conference on Rainwater Cistern Systems. Keelung, Taiwan.

CHU, S. C., LIAW, C. H., HUANG, W. L., HSU, S. K., TSAI, Y. L. & KUO, J. J. (1999) The Study for Influencing Factors of Urban Rainwater Catchment System. Proceedings of the 9th International Conference on Rainwater Catchment Cistern Systems. Petrolina, Brazil.

CIPHE (2010) Greenplumb. http://www.ciphe.org.uk/GreenPlumb/
Accessed 12 February 2010

CIRIA. (2000) Sustainable Urban Drainage Systems – Design Manual for England and Wales., Cromwell Press, Wiltshire.

CIRIA. (2005) SUDS management train.
http://www.ciria.org/suds/suds_management_train.htm Accessed 26 August 2007

CONAGUA (2009) Rainwater harvesting in rural schools in Mexico. Comision Nacional del Agua.
http://www.conagua.gob.mx/homeenglish.aspx Accessed 18 October 2009
COOMBES, P. & KUCZERA, G. (2001) Rainwater tank design for water supply and stormwater management. Stormwater Industry Association Regional Conference. Port Stephens, NSW, Australia.

COOMBES, P. & KUCZERA, G. (2003) Analysis of the performance of rainwater tanks in Australian capital cities. 28th International Hydrology and Water Resources symposium, 10th-14th November 2003. Wollogong, NSW, Australia.

COOMBES, P. J., ARGUE, J. R. & KUCZERA, G. (1999) Figtree Place: a case study in water sensitive urban development (WSUD). *Urban Water*, 1 (4), 335-343.

COOMBES, P. J., ARGUE, J. R. & KUCZERA, G. (2002) Figtree Place: a case study in water sensitive urban development (WSUD). University of Newcastle Report for Bonacci Water:
http://www.bonacciwater.com/research/subdivisions%20land%20dev%20-%2001%20-%20figtree%20place.pdf Accessed 03 July 2007

COOMBES, P. J. & BARRY, M. E. (2007) The effect of selection of time steps and average assumptions on the continuous simulation of rainwater harvesting strategies. *Water Science and Technology*, 55 (4), 125-133.

COOMBES, P. J., DUNSTAN, H., SPINKS, A. T., EVANS, C. & HARRISON, T. (2005) An overview of a decade of research into the quality of rainwater supplies collected from roofs. Proceedings of the 12th International Conference of the International Rainwater Catchment Systems Association. New Delhi, India.

COOMBES, P. J., DUNCAN, H., SPINKS, A. T., EVANS, C. & HARRISON, T. (2006) Key messages from a decade of water quality research into roof collected rainwater supplies. 1st National HYDROPOLIS Conference. Burswood Convention Centre, Perth, Western Australia.

CRABTREE, K. D., RUSKIN, R. H., SHAW, S. B. & ROSE, J. B. (1996) The detection of cryptosporidium oocyts and giardia cysts in cistern water in the U.S. Virgin Islands. *Water Research*, 30 (1), 208-216.

CRASTA, F. M., FASSO, C. A., PATTA, F. & PUTZU, G. (1982) Carthaginian-Roman Cisterns in Sardinia. Proceedings of the 1st International Conference on Rainwater Cistern Systems. Honolulu, Hawaii.

CRC (2005) Public Health Aspects of Rainwater Tanks in Urban Australia. Cooperative Research Centre for Water Quality and Treatment, Occasional Paper 10. ISBN 1876616431.

CRCCH (2005) MUSIC User Guide. CRCCH, Australia.

DAO, A. D., HAN, M., NGUYEN, V. A., HO, X. Q. & KIM, T. H. (2009) Flooding Mitigation Plan at Downtown of Hanoi by Rainwater Harvesting. The 8th International Conference on Urban Drainage Modelling and the 2nd International Conference on Rainwater Harvesting and Management. 7-12th September. Tokyo, Japan.

DART, C. (2007) Request for access to APART. Personal Communication, Email. 30 November 2007.

DAVIS, A. P., SHOKOUHIAN, M. & NI, S. (2001) Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere*, 44, 997-1009.

DBIS (2009) Statistical Press Release URN 09/92.
http://stats.bis.gov.uk/ed/sme Accessed 12 December 2009

DCC (2005) A Warm Response, Our Climate Change Challenge.
http://www.devon.gov.uk/climate-change-strategy.pdf Accessed 12 September 2007

DCLG (2006a) Building a greener future: towards zero carbon development. Product Code: 06SCDD04276.

DCLG (2006b) Code for Sustainable Homes: a step-change in sustainable home building practice. http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf
Accessed 26 May 2007

DCLG (2006c) PPS 25: development and flood risk.
http://www.communities.gov.uk/planningandbuilding/planning/planningpolicyguidance/planningpolicystatements/planningpolicystatements/
Accessed 26 May 2007

DCLG (2007) PPS 1: Sustainable development – climate change supplement.
http://www.communities.gov.uk/planningandbuilding/planning/planningpolicyguidance/planningpolicystatements/planningpolicystatements/
Accessed 26 May 2007

DCLG (2008) Draft planning policy statement: Eco-towns.
http://www.communities.gov.uk/archived/publications/planningandbuilding/ppsecotowns
Accessed 18 October 2008

DCLG (2009a) Circular 09/2009: The Building Regulations 2000 - Authorisation of New Competent Person Schemes, New Water Efficiency Calculation Methodology Publication, and Revocation of a Spent Provision on the Time Limit for Prosecution.

DCLG (2009b) Circular 10/2009: Postponement of the coming into force of the amendments made to Part G and other provisions of the Building Regulations.

DCLG and DEFRA (2006) Water Efficiency in New Buildings; a consultation document. Communities & Local Government Publications, UK.

DECC (2008) Climate Change Act 2008. http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx Accessed 14 January 2009

DE GRAAF, R. (2009) Innovations in Urban Water Management to Reduce the Vulnerability of Cities. Published PhD Thesis, Netherlands, Delft University of Technology. ISBN 9789085595915.

DEFRA (2002) Directing the flow: Priorities for future water policy. Crown Copyright, London.

DEFRA (2004) Making space for water - Developing a new Government strategy for flood and coastal erosion risk management in England. Crown Copyright, London.

DEFRA (2005) Securing the Future: delivering UK sustainable development strategy. Crown Copyright, London.

DEFRA (2007a) Funding and charging arrangements for sustainable urban drainage systems. Queen's Printer and Controller of H.M. Stationery Office.

DEFRA (2007b) Consultation on proposed changes to powers to restrict non-essential uses of water. Crown Copyright, London.

DFERA (2007c) Consultation on water metering in areas of serious water stress. PB12440, Crown Copyright, London.

DEFRA (2008a) A Framework for Pro-environmental Behaviours. Crown Copyright, London.

DEFRA (2008b) Consultation on The Private Water Supplies (England) Regulations 2008. Crown Copyright, London.

DEFRA (2008c) Future Water: The Government's water strategy for England. CM7319, Crown Copyright, London.

DEFRA (2008d) Improving surface water drainage: consultation to accompany proposals set out in the Government's water strategy, Future Water. Crown Copyright, London.

DEFRA (2008e) Progress Report on Sustainable Products and Materials. Crown Copyright, London.

DEFRA (2008f) Rainwater harvesting: future incentives discussion with Nieves Bottomley, Head of DEFRA Water Saving Group. Personal Communication, Email. 27 September 2008.

DEFRA (2009a) The Government's Response to Sir Michael Pitt's Review of the summer 2007 floods: Progress Report. Crown Copyright, London.

DEFRA (2009b) The independent review of charging for household water and sewerage services. Crown Copyright, London.

DEFRA (2009c) Public Understanding of Sustainable Water Use in the Home. Crown Copyright, London.

DEFRA (2010) Flood and Water Management Act: Hansard Reports. Crown Copyright, London. http://www.defra.gov.uk/environment/flooding/policy/fwmb/next.htm
Accessed 12 April 2010

DEFRA, DCLG, DBERR, DCMS and STRATEGIC FORUM FOR CONSTRUCTION (2007) Draft Strategy for Sustainable Construction: a consultation paper. Crown Copyright, London.

DEFRA & H.M. REVENUE & CUSTOMS (2007) Qualified Water Technology List - Enhanced Capital Allowances. http://www.eca-water.gov.uk/.
Accessed 18 August 2007

DER (1999) Low-Impact Development Design Strategies: An Integrated Design Approach. Largo, Maryland, USA, DER.

DER (2009) National Rainwater and Greywater Initiative: Household Rebate Guidelines. http://www.environment.gov.au/water/programs/nrgi/pubs/nrgi-guidelines-application.pdf. Australia, Australian Government.
Accessed 30 July 2009

DEWHA (2009) National Rainwater and Greywater Initiative: Household Rebate Guidelines. http://www.environment.gov.au/water/programs/nrgi/pubs/nrgi-guidelines-application.pdf. Accessed 30 July 2009

DGNB (2009) German Sustainable Building Certificate.
http://www.dgnb.de/fileadmin/downloads/DGNB_system_en_44S_20091217_ohneblatt.pdf.
Accessed 12 November 2009

DILMAN, D. A. (1978) Mail and Telephone Surveys: The Total Design Method. Wiley-Interscience, Chichester.

DIN (1989) Rainwater harvesting systems — Part 1: Planning, installation, operation and maintenance. Translated from the German DIN by Kern GmbH, Frankfurt, Germany.

DIXON, A. (2000) Simulation of Domestic Water Re-use Systems: Greywater and Rainwater in Combination. Unpublished PhD Thesis, Department of Civil and Environmental Engineering. Imperial College of Science, Technology and Medicine, London.

DIXON, A., BUTLER, D. & FEWKES, A. (1999) Water Saving Potential of Domestic Water Reuse Systems Using Greywater and Rainwater in Combination. *Water Science and Technology*, 39 (5), 25-32.

DTI (2006) Global Watch Mission Report: Water recycling and reuse in Singapore and Australia. DTI and British Water, London.

DUANY, A. (2009) SmartCode Basics, SmartCode Line by Line and The SmartCode Module. http://www.dpz.com/services_lectures.htm.
Accessed 12 December 2009

DYER, K. (2010) Utility Bills for the Innovation Centre. Personal Communication, Email. University of Exeter. 18 February 2010.

EA (2005) UK Water Consumption. http://www.environment-agency.gov.uk/commondata/103196/s3-3a_houseuse?referrer=/yourenv/432430/432434/432453/434390/.
Accessed 12 May 2007

EA (2007) Conserving water in buildings: a practical guide. GEHO1107BNJR-E-E.

EA (2008a) Greenhouse gas emissions of water supply and demand management options. Science Report - SC070010. Environment Agency for England and Wales.

EA (2008b) Harvesting rainwater for domestic uses: an information guide. http://www.environment-agency.gov.uk/homeandleisure/drought/38559.aspx
Accessed 25 May 2008

EA (2009) Water for People and the Environment: Water Resources Strategy for England and Wales., Environment Agency for England and Wales.

EA (2010) Energy and Carbon Implications of Rainwater Harvesting & Greywater Recycling – Draft Final Report. UNPUBLISHED. EA, London, CONFIDENTIAL.

EC (2005) The new SME definition: user guide and model declaration. Enterprise and Industry Publications, Publications Office.

ECKENFELDER, W. W. & ARGAMAN, Y. (1991) Principles of Biological and Physical/Chemical Nitrogen Removal. IN SEDLAK, R. (Ed.) Phosphorus and nitrogen removal from municipal wastewater: principles and practice. Second ed. Lewis Publishers, USA.

ELLIOTT, A. H. & TROWSDALE, S. A. (2007) A review of models for low impact urban stormwater drainage. *Environmental Modelling and Software*, 22 (3), 394-405.

ELLIS, M. (2010) Hydrology and Planning - the Policy Context. BHS National Meeting. Liverpool, UK.
ENHEALTH (2004) Guidance on use of rainwater tanks. Australian Government. ISBN 0 642 82443 6.

ENVIROWISE (2008) Reducing mains water use through rainwater harvesting. Leaflet EN896.

ENVIROWISE (2010) Water. Use it. Don't waste it. http://actonco2.direct.gov.uk/actonco2/home/campaigns/save-water.html. London, Waterwise.
Accessed 01 April 2010

EST (2009) Life + Water and Energy Project. http://www.energysavingtrust.org.uk/corporate/Corporate-and-media-site/Key-initiatives/New-services-from-the-Energy-Saving-Trust/Life-Water-and-Energy-Project. Accessed 01 April 2009

EVANS, C. A., COOMBES, P. J. & DUNSTAN, R. H. (2006a) Wind, rain and bacteria: The effect of weather on the microbial composition of roof-harvested water. *Water Research*, 40, 37-44.

EVANS, C. A., COOMBES, P. J., DUNSTAN, R. H. & HARRISON, T. (2006b) Identifying the Major Influences on the Microbial Composition of Roof Harvested Rainwater and the Implications for Water Quality. The 7th International Conference on Urban Drainage and 4th International Conference on Water Sensitive Urban Design. Melbourne, Australia.

FEWKES, A. (1999a) The use of rainwater for WC flushing: the field testing of a collection system. *Building and Environment*, 34, 765-772.

FEWKES, A. (1999b) Modelling the performance of rainwater collection systems: towards a generalised approach. *Urban Water*, 1, 323-333.

FEWKES, A. (2004) The Modelling and Testing of a Rainwater Catchment System in the UK. Unpublished PhD Thesis, Nottingham Trent University, UK.

FEWKES, A. (2006) The Technology, design and utility of rainwater catchment systems. IN BUTLER, D. & MEMON, F. (Eds.) (2006) Water Demand Management. IWA Publishing, UK.

FEWKES, A. & BUTLER, D. (2000) Simulating the performance of rainwater collection and reuse systems using behavioural models. *Buildings Service Engineering Research and Technology*, 21 (2), 99-106.

FEWKES, A. & WARM, P. (2000) Method of Modelling the performance of rainwater collection systems in the United Kingdom. *Building Services Engineering Research and Technology*, 2 (4), 257-265.

FEWTRELL, L. & KAY, D. (2007a) Microbial quality of rainwater supplies in developed countries – a review. *Urban Water*, 4 (4), 253-260.

FEWTRELL, L. & KAY, D. (2007b) Quantitative microbial risk assessment with respect to Campylobacter spp. in toilets flushed with harvested rainwater. *Water and Environment Journal*, 21, 275-280.

FEWTRELL, L. & KAY, D. (2008) Health Impact Assessment for Sustainable Water Management. IWA Publishing, London.

FEWTRELL, L., KAY, D. & MCDONALD, A. (2008) Rainwater harvesting - an HIA of rainwater harvesting in the UK. IN FEWTRELL, L. and Kay, D. (Ed.) (2008) Health Impact Assessment for Sustainable Water Management. IWA Publishing, London.

FEWTRELL, L., DAVIES, C., KAY, D., WATKINS, J. & WYER, M. (2009) Acquisition of microbial data on quality of harvested rainwater in the United Kingdom to drive a quantitative microbial risk assessment. Experiences with Rainwater Harvesting and Greywater Recycling and their Future Prospects, Aqua enviro. Birmingham, UK.

FLAHAUT, S., HARTKE, A., GIARD, J.-C. & AUFFRAY, Y. (1997) Alkaline stress response in Enterococcus faecalis: Adaptation, Cross-Protection, and Changes in Protein Synthesis. *Applied and Environmental Microbiology*, 63 (2), 812-814.

FORSTER, J. (1999) Variability of Roof Runoff Quality. *Water Science and Technology*, 39 (5), 137-144.

FRASER, S. L., LIM, J., DONSKEY, C. J. & SALATA, R. A. (2009) Enterococcal Infections. Emedicine, http://emedicine.medscape.com/article/216993-overview. Accessed 12 December 2009

GARDNER, T., BEAL, C., HOOD, B., LANE, J., CHRISTIANSEN, C., MILLAR, G., VIERITZ, A. & CHAPMAN, H. (2008) Benchmarking Water Sensitive Urban Design - Payne Road. Research Report 77. ISBN 18766 1627X, CRCWQRA (Cooperative Research Centre Water Quality Research Australia).

GEELS, F. W. (2002) Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study. *Research Policy*, 31, 1257-1274.

GEELS, F. W. & SCHOT, J. (2007) Typology of sociotechnical transition pathways. *Research Policy*, 36, 399-417.

GERETSHAUSER, G. & WESSELS, K. (2007) The stormwater management information system – a GIS portal for the close-to-nature management of stormwater in the Emscher region. Proceedings of the 6th International Conference on Sustainable Techniques and Strategies in Urban Water Management (Novatech). 24-28 June 2007, Lyon, France.

GEROLIN, A. (2010) Discussion on Standards for Rainwater Harvesting Systems. Personal Communication, Email. French Department of the Environment (MEEDDM), CETE de l'Est, Stormwater Management and Planning Division. 17 January 2010.

GHANAYEM, M. (2001) Environmental considerations with respect to rainwater harvesting. 10th International Rainwater Catchment Systems Conference. Mannheim, Germany.

GHISI, E. (2006) Potential for potable water savings by using rainwater in the residential sector of Brazil. *Building and Environment*, 41, 1544-1550.

GILG, A. & BARR, S. (2006) Behavioural attitudes towards water saving? Evidence from a study of environmental actions. *Ecological Economics*, 57, 400-414.

GILL, R. D. (2000) The Great Maya Droughts; Water, Life and Death. University of New Mexico Press, Albuquerque, New Mexico.

GIUPPONI, C. (2007) Decision Support Systems for implementing the European Water Framework Directive: The MULINO approach. *Environmental Modelling and Software*, 22, 248-258.

GLAVIC, P. & LUKMAN, R. (2007) Review of sustainability terms and their definitions. *Journal of Cleaner Production*, 15 (18), 1875-1885.

GOODHEW, S., FITZGERALD, D. & SOUTHCOMBE, C. (1999) Water efficient dwellings; Do UK house builders recognise a need? *Journal of Financial Management of Property and Construction*, 4 (2), 49-62.

GOULD, J. (1999) Is rainwater safe to drink? A review of recent findings. Proceedings of the 9th International Rainwater Catchment Systems Conference. Petrolina, Brazil.

GOULD, J. & NISSEN-PETERSON, E. (1999) Rainwater catchment systems for domestic supply: design, construction and Implementation. Intermediate Technology Publications, London.

GRIGSON, J. (2010) Discussion regarding omission of first flush devices from BS 8515:2009. Personal Communication, Email. University of Exeter. 17 January 2010.

HAN, M. (2009) Korean traditional Rain Culture and Technology and its modern application for climate change adaptation. The 8th International Conference on Urban Drainage Modelling and the 2nd International Conference on Rainwater Harvesting and Management. 7-12th September. Tokyo, Japan.

HANDIA, L., MADALITSO TEMBO, J. & MWIINDWA, C. (2003) Potential of rainwater harvesting in urban Zambia. *Physics and Chemistry of the Earth*, 28, 893-896.

HARDIE, M. (2010) Rainwater Storage Gutters for Houses. *Sustainability*, 2, 266-279.

HARTKE, A., GIARD, J.-C., LAPLACE, J.-M. & AUFFRAY, Y. (1998) Survival of Enterococcus faecalis in an oligotrophic microcosm: changes in morphology, development of general stress resistance and analysis of protein synthesis. *Applied and Environmental Microbiology*, 64 (11), 4238-4245.

HASSELL, C. (2005) Rainwater harvesting in the UK – a solution to increasing water shortages? Proceedings of the 12th International Conference on Rainwater Catchment Cistern Systems. New Delhi, India.

HATTON-MACDONALD, D. & DYACK, B. (2004) Exploring the Institutional Impediments to Conservation and Water Reuse - National Issues. Report S//04/221 for CSIRO.

HAUBER-DAVIDSON, G. (2007) Large Commercial Rainwater Harvesting Projects. Proceedings of the Rainwater and Urban Drainage Conference. 21-27 August. Sydney, Australia.

HAYES, N. (2000) Doing Psychological Research: Gathering and analysing data. Open University Press, Philadelphia.

HERRMANN, T. & SCHIMDA, U. (1999) Rainwater Utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects. *Urban Water*, 1, 307-316.

HODGSON, M. (2008) Discussion on rainwater harvesting and SMEs. South West Sustainable Business Manager, Global Action Plan. Personal Communication, Email. 10 December 2008.

HOLLANDER, R., BULLERMANN, M., GROSS, C., HARTUNG, H., KONIG, K. W., LUCKE, F. K. & NOLDE, E. (1996) Microbial public health aspects in the use of rain water as water reservoirs for toilet flushing, garden irrigation and laundry. *Gesundheitswesen*, 58 (5), 288-293.

HORAK, H. M., CHYNOWETH, J. S., MYERS, W. P., DAVIS, J., FENDORF, S. & BOEHM, A. B. (2010) Microbial and metal water quality in rain catchments compared with traditional drinking water sources in the East Sepik Province, Papua New Guinea. *Journal of Water and Health*, 8 (1), 126-138.

HOUSE OF LORDS (2007) Water Management Follow-up Report. 2nd Report of Session 2006-07. The Stationery Office Ltd, London.

HURLEY, L., MOUNCE, S. R., ASHLEY, R. M. & BLANKSBY, J. R. (2008) No Rainwater in Sewers (NORIS): assessing the relative sustainability of different retrofit solutions. 11th International Conference on Urban Drainage. Edinburgh, Scotland, UK.

HURLIMANN, A. (2006) Melbourne office worker attitudes to recycled water. *Water, Journal of the Australian Water Association*, November Issue, 32-36.

HURLIMANN, A. (2007a) Attitudes to future use of recycled water in a Bendigo office building. *Water, Journal of the Australian Water Association*, September Issue, 42-46.

HURLIMANN, A. (2007b) Is recycled water risky? An Urban Australian community's perspective. *The Environmentalist*, 27 (1), 83-94.

IKEBUCHI, S. & FURUKAWA, S. (1982) Feasibility Analysis of Rain Water Cistern Systems as an Urban Water Supply Source. Proceedings of the 1st International Conference on Rainwater Cistern Systems. Honolulu, Hawaii.

JACKSON, R. (2009) Occupancy of the Innovation Centre. Personal Communication, Email. University of Exeter. 23 March 2009.

JEFFREY, P. & SEATON, R. A. F. (2004) A Conceptual Model of 'Receptivity' Applied to the Design and Deployment of Water Policy Mechanisms. *Environmental Sciences*, 1 (3), 277-300.

JENKINS, D., PEARSON, F., MOORE, E., SUN, J. K. & VALENTINE, R. (1978) Feasibility of rainwater collection systems in California., Contribution No. 173, Californian Water Resources Centre, University of California.

JORDAN, F. L., SEAMAN, R., RILEY, J. J. & YOKLIC, M. R. (2008) Effective removal of microbial contamination from harvested rainwater using a simple point of use filtration and UV-disinfection device. *Urban Water*, 5 (3), 209-218.

KAY, D., FLEISHER, R. L., SALMON, R. L., JONES, F., WYER, M. D., GODFREE, A. F., ZELENAUCH-JACQUOTTE, Z. & SHORE, R. (1994) Predicting likelihood of gastroenteritis from sea bathing: results from randomised exposure. *The Lancet*, 344, 905-909.

KELLAGHER, R. & MANEIRO FRANCO, E. (2005) Rainfall collection and use in developments; benefits for yield and stormwater control. WaND Briefing Note 19; WP2 Briefing Note 2.15; Report SR 677 Release 2.0 (Nov 2005). WaND, HR Wallingford.

KIM, R. H., LEE, S., LEE, J. H. & KIM, Y. M. (2007) Design of Rainwater Management System for Eco-Housing Complex. Proceedings of the Rainwater and Urban Design Conference. 21-23 August. Sydney, Australia.

KIM, Y. & HAN, M. (2006) A Rainfall-Storage-Runoff (RSR) model for the design of a rainwater tank effective for flow control in urban drainage pipes. The 2nd IWA International Rainwater Harvesting Workshop. Beijing, China.

KING, N. (2004) Using Templates in the Thematic Analysis of Text. IN CASSELL, C. and SYMON, G. (Ed.) Qualitative Methods in Organizational Research. Sage, London.
KINKADE-LEVARIO, H. (2003) Rainwater Harvesting Used in Low-Impact Development Design Guidelines. Proceedings of the 1st American Rainwater Harvesting Conference, American Rainwater Catchment Systems Association. Austin, Texas.

KINNEAR, P. R. & GRAY, C. D. (2008) SPSS 15 Made Simple. Psychology Press, UK.

KONIG, K. W. (2001) The Rainwater Technology Handbook: Rainwater Harvesting in building. Wilo-Brain, Dortmund.

LATHAM, B. G. (1983) Rainwater collection systems: the design of single purpose reservoirs. Unpublished MSc Thesis, University of Ottawa, Canada.

LEE, K. T., LEE, C.-D., YANG, M.-S. & YU, C.-C. (2000) Probabilistic Design of Storage Capacity for Rainwater Cistern Systems. *Journal of Agricultural Engineering Research*, 77 (3), 343-348.

LEGGETT, D. J., BROWN, R., BREWER, D., STANFIELD, G. & HOLIDAY, E. (2001) Rainwater and greywater use in buildings: Best practice guidance (C539). CIRIA, London.

LI ROSI, O., CASARCI, M., MATTIOLI, D. & DE FLORIO, L. (2007) Best available technique for water reuse in textile SMEs. *Desalination*, 206, 614-619.

LIAW, C.-H. & TSAI, Y.-L. (2004) Optimum Storage Volume of Rooftop Rain Water Harvesting Systems for Domestic Use. *Journal of the American Water Resources Association*, 40, 901-912.

LIU, S., MAKROPOULOS, C., BUTLER, D. & MEMON, F. (2006) An object based household water cycle model: concept and construction. The 7th International Conference on Urban Drainage and 4th International Conference on Water Sensitive Urban Design. Melbourne, Australia.

LUCAS, S. A., COOMBES, P. J., HARDY, M. J. & GEARY, P. M. (2006) A comparative study of common uses of selected modelling tools for evaluating rainwater harvesting strategies. The 7th International Conference on Urban Drainage and 4th International Conference on Water Sensitive Urban Design. Melbourne, Australia.

LUCAS, S. A., COOMBES, P. J. & SHARMA, A. K. (2010) The impact of diurnal water use patterns, demand management and rainwater tanks on water supply network design. *Water Science and Technology: Water Supply*, 10 (1), 69-80.

LUKACS, E. (2005) The economic role of SMEs in world economy, especially in Europe. *European Integration Studies, Miskolc*, 4 (1) 3-12.

LUKER, M. & MONTAGUE, K. (1994) Control of pollution from highway drainage discharges. Report 142. CIRIA, London.

LUSHEN, S., HUILONG, L. and YONGSHENG, W. (2007) Rainwater quality in water cellars and pollution-prevention measures. Proceedings of the Rainwater and Urban Design Conference, 21-27 August. Sydney, Australia.

LYE, D. (2002) Health risks associated with consumption of untreated water from household roof catchment systems. *Journal of the American Water Resources Association*, 38 (5), 1301-1306.

MACNAGHTEN, P. & URRY, J. (1998) Contested Natures. Sage, London.

MAGYAR, M. I., MITCHELL, V. G., LADSON, A. R. & DIAPER, C. (2007) Investigating sediment dynamics in a laboratory rainwater tank. Proceedings of the Rainwater and Urban Design Conference, 21-27 August. Sydney, Australia.

MAKROPOULOS, C., NATSIS, K., LIU, S., MITTAS, K. & BUTLER, D. (2008) Decision Support for Sustainable Option Selection in Integrated Urban Water Management. *Environmental Modelling and Software*, 23 (12) 1448-1460.

MARSDEN JACOB ASSOCIATES (2007) The cost-effectiveness of rainwater tanks in urban Australia. National Water Commission, Australian Government. http://www.nwc.gov.au/resources/documents/cost-effectiveness-rainwater-tanks-body-waterlines-0407.pdf Accessed 12 January 2008

MARSH, T. J. & HANNAFORD, J. (2007) The summer 2007 floods in England and Wales - a hydrological appraisal. Centre for Hydrology and Ecology, Wallingford.

MARTIN, A. R., COOMBES, P. J., DUNSTAN, R. H., EVANS, C. & MORROW, A. (2007a) The passage of direct precipitation to rainwater storage: A case study; Newcastle, Australia. Proceedings of the Rainwater and Urban Design Conference, 21-27 August. Sydney, Australia.

MARTIN, C., RUPERD, Y. & LEGRET, M. (2007b) Urban stormwater drainage management: The development of a multicriteria decision aid approach for best management practices. *European Journal of Operational Research*, 181, 338-349.

MAXWELL, M. & THORNELL, M. (2009) Liverpool Hospital Stage 2 Redevelopment - Equity-focused Health Impact Assessment. Sydney, Sydney South West Area Health Service. http://www.hiaconnect.edu.au/reports/EFHIA_Liverpool_Hospital_Phase_2.pdf. Accessed 12 October 2009

MAY, S. & PRADO, R. T. A. (2006) Experimental evaluation of rainwater quality for non-potable applications in the city of Sao Paulo, Brazil. *Urban Water*, 3 (3), 145-151.

MCCANN, B. (2007) Rain gains: the rise of rainwater harvesting. *Water 21*, IWA magazine, February Issue, 13-14.

MCCARTHY, N. (2006) Philosophy in the making. *Ingenia*, 26 (March), 47-51.

MEADOWS, D. H., MEADOWS, D. L., RANDERS, J. & BEHRENS III, W. W. (1972) Limits to Growth. Earth Island, MIT, USA.

MEERA, V. & AHAMMED, M. (2006) Water quality of rooftop rainwater harvesting systems: a review. *Journal of Water Supply Research and Technology-Aqua*, 55 (4), 257-268.

MEERA, V. & AHAMMED, M. M. (2008) Solar disinfection for household treatment of roof-harvested rainwater. *Water Science and Technology: Water Supply*, 8 (2), 153-160.

MEMON, F. A., FIDAR, A., LOBBAN, A., DJORDEVIC, S. & BUTLER, D. (2009) Modelling the effectiveness of rainwater harvesting as a stormwater management option. 33rd IAHR Congress - Water Engineering for Sustainable Environment. Vancouver, Canada.

MET OFFICE (2007) 1961-1990 Averages. http://www.metoffice.gov.uk/climate/uk/averages/19611990/index.html. Accessed 28 August 2007

MIKKELSEN, P. S., ADELAR, O. F., ALBRECHTSEN, H.-J. & HENZE, M. (1999) Collected rainfall as a water source in Danish households – what is the potential and what are the costs? *Water Science and Technology*, 39 (5), 49-56.
MITCHELL, V. G. (2004) Australian water conservation and reuse research program: integrated urban water management, a review of current Australian practice. Joint report for AWA and CSIRO, CMIT-2004-075. ISBN0643091874.

MITCHELL, V. G. (2005) Aquacycle - user guide. http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit.woa/1/wa/downloadDocumentation?id=1000144&wosid=wMS1qLE1yJcSTA16s8XFa0
Accessed 14 July 2007

MITCHELL, V. G., DUNCAN, H., INMAN, M., RAHILLY, M., STEWART, J., VIERITZ, A., HOLT, P., GRANT, A., FLETCHER, T., COLEMAN, J., SHIROMA, M., SHARMA, A., DELECTIC, A. & BREEN, P. (2007) Integrated Urban Water Modelling - Past, Present and Future. Proceedings of the 13th International Rainwater Catchment Systems Conference and 5th International Water Sensitive Urban Design Conference. Sydney, Australia.

MODDEMEYER, S., FLEMING, P., LILLY, D. & SCHIMEK, G. (2003) Seattle Public Utilities Rainwater Harvesting Pilot Project. Proceedings of the 1st American Rainwater Harvesting Conference, American Rainwater Catchment Systems Association. Austin, Texas.

MORROW, A. C., DUNSTAN, R. H. & COOMBES, P. J. (2009) Contaminants of Rainwater Harvesting Systems (RWHS) in Eastern & Southern Australia. 14th International Conference on Rainwater Catchment Systems. Kuala Lumpur, Malaysia.

MUN, J., HAN, M., HAN, M. & KIM, S. (2009) Rainwater Tank for Preventing Sewer Flooding. Internal paper, Seoul National University, Korea.

MURASE, M. (2009) Innovative Rainwater Museum in Japan. The 8th International Conference on Urban Drainage Modelling and the 2nd International Conference on Rainwater Harvesting and Management. 7-12th September. Tokyo, Japan.

NAJI, F. & LUSTIG, T. (2006) On-site water recycling - a total water cycle management approach. *Desalination*, 188, 195-202.
NCI (2009) NCI Charrette System: The Breakthrough Planning Tool for Community Transformation. http://www.charretteinstitute.org/.
Accessed 18 November 2009

NEKE, K., SCHOEMAKER, A., JANTOWSKI, B. & MEERMAN, R. (2009) Building an institutional rainwater harvesting framework; the RAIN model and its challenges. 14th International Conference on Rainwater Catchment Systems. Kuala Lumpur, Malaysia.

NGIGI, S. N. (1999) Optimisation of rainwater catchment system design parameters in the arid and semi arid lands of Kenya. Proceedings of the 9th International Conference on Rainwater Catchment Cistern Systems. Petrolina, Brazil.

NOLDE, E. (2007) Possibilities of rainwater utilisation in densely populated areas including precipitation runoffs from traffic surfaces. *Desalination*, 215, 1-11.

NORTON, M. (2010) Regulated Water Management.
http://www.edie.net/library/view_article.asp?id=5351.
Accessed 30 March 2010

NWC (2009) National Water Initiative.
http://www.nwc.gov.au/www/html/117-national-water-initiative.asp
Accessed 27 March 2009

OFWAT (2008) Water Supply and Demand Policy.
http://www.ofwat.gov.uk/pricereview/pap_pos_pr09supdempol.pdf. London, OFWAT.
Accessed 30 November 2008

OPPENHEIM, A. N. (2005) Questionnaire Design, Interviewing and Attitude Measurement. London, Continuum.

OSMAN AKAN, A. & HOUGHTALEN, R. J. (2003) Urban Hydrology, Hydraulics and Stormwater Management: Engineering Applications and Computer Modelling. John Wiley and Sons Inc, New Jersey.

PALISADE (2010) Guide to using @risk version 5.5.
http://www.palisade.com/risk/default.asp.
Accessed 27 January 2010

PARKINSON, J., SCHUTZE, M. & BUTLER, D. (2007) Modelling the impacts of domestic water conservation on the sustainability of the urban sewerage system. *Water and Environment Journal*, 19 (1), 49-56.

PARSONS, D., GOODHEW, S., FEWKES, A. & DE WILDE, P. (2010) The perceived barriers to the inclusion of rainwater harvesting systems by UK house building companies. *Urban Water*, (In Press).

PARTZSCH, L. (2009) Smart regulation for water innovation - the case of decentralized rainwater technology. *Journal of Cleaner Production*, 17, 985-991.

PATTERN, M. Q. (1990) Qualitative evaluation and research methods. Sage, Newbury Park, California.

PETERS, E. J. (2006) Rainwater potential for domestic water supply in Grenada. *Proceedings of the Institution of Civil Engineers; Water Management Magazine*, 159, 147-153.

PETERS, E. J. (2007) Sizing of Rainwater Cisterns for Domestic Water Supply in the Grenadines. University of the West Indies.
http://www.cavehill.uwi.edu/bnccde/svg/conference/papers/peters.html.
Accessed 12 December 2007

PITT, M. (2008) Learning lessons from the 2007 floods. The 'Pitt Review', London.

PLAZINSKA, A. (2001) Microbiological quality of rainwater in selected indigenous communities in Central Australia. 10th International Rainwater Catchment Systems Conference, Mannheim, Germany.

POELSMA, P., MCCARTHY, D. T., DELECTIC, A., SCHANG, C., FLETCHER, T. D. & DEVAUCHELLE, E. (2009) The design, installation and monitoring of a novel stormwater harvesting system. The 8th International Conference on Urban Drainage Modelling and the 2nd International Conference on Rainwater Harvesting and Management. 7-12th September. Tokyo, Japan.

PRESSMAN, J. L. & WILDAVSKY, A. (1984) Implementation. University of California Press, Berkeley.

PUSHARD, D. (2004) Austin's Zilker Park Showcases Rainwater Harvesting. http://www.harvesth2o.com/zilker.shtml.
Accessed 12 April 2007

QSR (2009) NVivo 8. http://www.qsrinternational.com/products_nvivo.aspx.
Accessed 12 October 2009
RAE (2004) Design principles: the engineer’s contribution to society. http://www.raeng.org.uk/education/vps/pdf/design_principles.pdf
Accessed 08 May 2008

RAJABU, K. R. M. (2005) The role of participatory problem analysis in performance improvement and sustainable management of rainwater harvesting (RWH) systems: A case study of Makanya village, Tanzania. *Physics and Chemistry of the Earth*, 30, 832-839.

RAVEN, R. P. J. M., MOURIK, R. M., FEENSTRA, C. F. J. and HEISKANEN, E. (2009) Modulating societal acceptance in new energy projects: Towards a toolkit methodology for project managers. *Energy*, 34, 564-574.

REED, J. (2009) In search of the one-litre drop.
Water & Effluent Treatment News, March 2009, Page 8.
http://www.edie.net/library/view_article.asp?id=4950.
Accessed 30 March 2009

RENN, O., WEBLER, T., RAKEL, H., DIENEL, P. AND JOHNSON, B. (1993) Public participation in decision making: A three-step procedure. *Policy Sciences*, 26, 189-214.

RETAMAL, M., GLASSMIRE, J., ABEYSURIYA, K., TURNER, A. & WHITE, S. (2009) The water-energy nexus: investigation into the energy implications of rainwater systems., Institute for Sustainable Futures, University of Technology Sydney and CSIRO.
http://epress.lib.uts.edu.au/dspace/bitstream/handle/2100/888/retamaletal2009waterenergynexus.pdf?sequence=4
Accessed 12 March 2010

RETAMAL, M., TURNER, A. & WHITE, S. (2009) The water-energy-climate nexus - systems thinking and virtuous circles. Efficient 2009. Sydney, Australia.

REUTERS (2009) UK population seen rising 10 million in next 25 years.
http://uk.reuters.com/article/idUKTRE59K2G020091021
Accessed 21 February 2010

ROAF, S. (2006) Drivers and barriers for water conservation and reuse in the UK. IN BUTLER, D. & MEMON, F. A. (Eds.) (2006) Water Demand Management. IWA Publishing, London.

ROBINSON, P. (2006) Canadian Municipal Response to Climate Change: Measurable Progress and Persistent Challenges for Planners. *Planning Theory & Practice*, 7 (2), 218-223.

ROBSON, C. (2002) Real World Research. Blackwell, Oxford.

ROEBUCK, R. M. (2008) A Whole Life Costing Approach For Rainwater Harvesting Systems. Unpublished PhD Thesis, School of Engineering, Design and Technology. University of Bradford, Bradford.

ROEBUCK, R. M. & ASHLEY, R. M. (2007) Predicting the hydraulic and life-cycle cost performance of rainwater harvesting systems using a computer based modelling tool. *Water Practice and Technology*, 2 (2).

ROGERS, E. M. (1995) Diffusion of Innovations. The Free Press, New York.

SAKAKIBARA, T. (2009) Challenge to sustainable urban stormwater management in Japan. The 8th International Conference on Urban Drainage Modelling and the 2nd International Conference on Rainwater Harvesting and Management. 7-12th September. Tokyo, Japan.

SAKELLARI, I., MAKROPOULOS, C., BUTLER, D. & MEMON, F. (2005) Modelling sustainable urban water management options. *Proceedings of the Institution of Civil Engineers; Engineering Sustainability* 158, ES3, 143-153.

SAZAKLI, E., ALEXOPOULOS, M. & LEOTSINIDIS, M. (2007) Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece. *Water Research*, 41, 2039-2047.

SCHETS, F. M., ITALIAANDER, R., VAN DEN BERG, H. H. J. L. & DE RODA HUSMAN, A. M. (2010) Rainwater harvesting: quality assessment and utilization in The Netherlands. *Journal of Water and Health*, 8 (2), 224-235.

SCHILLER, E. J. & LATHAM, B. (1982) Computerized Methods in Optimizing Rainwater Catchment Systems. Proceedings of the 1st International Conference on Rainwater Cistern Systems. Honolulu, Hawaii.

SEFTON, C. (2009) Public engagement with sustainable water management. Unpublished PhD Thesis. University of Bradford, Bradford.

SEVERN TRENT WATER (2009) Surface Water Drainage: how to claim a lower sewerage charge. Leaflet WM 2009/10.035 TB. Severn Trent Water, Birmingham.

SHAFFER, P., ELLIOTT, C., REED, J., HOLMES, J. & WARD, M. (2004) Model agreements for sustainable water management systems. Report C626., CIRIA, UK.

SHARP, L. (2006) Water Demand Management in England and Wales: Construction of the Domestic Water User. *Journal of Environmental Planning and Management*, 49 (6), 869-889.

SHIRLEY-SMITH, C., CHEESEMAN, C. & BUTLER, D. (2008) Sustainability of water management in Zaragoza city. *Water and Environment Journal*, 22 (4), 287-296.

SIMMONS, G., HOPE, V., LEWIS, G., WHITMORE, J. & GAO, W. (2001) Contamination of potable runoff-collected rainwater in Auckland, New Zealand. *Water Research*, 35 (6), 1518-1524.

SMART WATER FUND (2005) Rainwater Tank Public Awareness Campaign. http://www.smartwater.com.au/projects/round2/davey/Documents/DaveyProducts_ProjectReport.pdf.
Accessed 15 November 2008

SMITH, C. (2010) National Flood Forum Annual Conference Speech. http://www.environment-agency.gov.uk/static/media/National_Flood_Forum_speech_Feb_2010.final.pdf.
Accessed 17 March 2010

SOUTH WEST WATER (2009) Charging for waste water disposal. Leaflet 901142/09 . South West Water, Exeter.

SPINKS, A. T., COOMBES, P., DUNSTAN, H. & KUCZERA, G. (2003) Water Quality Treatment Processes in Domestic Rainwater Harvesting Systems. The Institution of Engineers, Australia 28th International Hydrology and Water Resources Symposium. Wollongong, Australia.

SRIVASTAVA, R. C. (2001) Methodology for design of water harvesting system for high rainfall areas. *Agricultural Water Management*, 47, 37-53.

STANDARDS AUSTRALIA (2006) National Rainwater Tank Design and Installation Handbook. http://www.arid.asn.au/#.
Accessed 27 June 2008

STILL, G. T. & THOMAS, T. (2003) Sizing and optimally locating guttering for rainwater harvesting. Proceedings of the 11th International Rainwater Catchment Systems Association Conference. Mexico City, Mexico.

STORE, T. (2009) GAP SME Sustainability Database. Personal Communication, Email. University of Exeter. 14 April 2009.

SUGAI, M. (2009) Stormwater control measures for Tokyo. The 8th International Conference on Urban Drainage Modelling and the 2nd International Conference on Rainwater Harvesting and Management. 7-12th September. Tokyo, Japan.

SWCCIP (2003) Warming to the idea: meeting the challenge of climate change in the South West. http://www.oursouthwest.com/climate/scopingstudy.htm
Accessed 15 April 2007

TAKEDA, S., TAMADA, A., MATSUSHIMA, O., TAKASE, Y., MIYAHARA, S. & MIURA, A. (2009) Research of small-scale stormwater storage and/or infiltration system. The 8th International Conference on Urban Drainage Modelling and the 2nd International Conference on Rainwater Harvesting and Management. 7-12th September. Tokyo, Japan.

TENON FORUM (2008) Report on Entrepreneurial Britain: Wave 11. Tenon Forum. www.tenongroup.com.
Accessed 28 March 2009

THAT, L. T. (2005) Investigation of water consumption and wastewater discharge patterns using domestic water consumption records. Unpublished Ph D Thesis, Department of Civil and Environmental Engineering. Imperial College, London.

THOMAS, T. (2006) Domestic Roofwater Harvesting Research Programme. http://www.eng.warwick.ac.uk/dtu/rwh/index.html. Development Technology Unit, University of Warwick.
Accessed 15 May 2007

THOMPSON, E. R. & PHUA, F. T. T. (2005) Reliability among senior managers of the Marlowe-Crowne short-form social desirability scale. *Journal of Business and Psychology*, 19 (4), 541-554.

TSIHRINTZIS, V. A. & HAMID, R. (1997) Modelling and Management of Urban Stormwater Runoff Quality: A Review. *Water Resources Management*, 11, 137-164.

TWDB (2005) The Texas Manual on Rainwater Harvesting. TWDB, Austin, Texas..

TYSON, R. V., SIMONNE, E. H., DAVIS, M., LAMB, E. M., WHITE, J. M. & TREADWELL, D. D. (2007) Effect of nutrient solution, nitrate-nitrogen concentration and pH on nitrification rate in perlite medium. *Journal of Plant Nutrition*, 30 (4-6), 901-913.

UNEP (2009) Rainwater harvesting and utilisation: Examples of rainwater harvesting and utilisation around the world.
http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/9.asp.
Accessed 09 May 2009

UNITED UTILITIES (2009) Surface water and highway drainage: Site area charging 2009-2010: an explanation of site area charging for our measured non-household customers. Leaflet 03/09/SD/3529. United Utilities, Warrington.

VAES, G. & BERLAMONT, J. (1999) The Impact of Rainwater Reuse on CSO Emissions. *Water Science and Technology*, 39 (5), 57-64.

VAES, G. & BERLAMONT, J. (2001) The effect of rainwater storage tanks on design storms. *Urban Water*, 3, 303-307.

VAN DER STERREN, M., RAHMAN, A., BARKER, G., RYAN, G. & SHRESTHA, S. (2007) Rainwater Tanks for On-site Detention in Urban Developments in Western Sydney: An Overview. Proceedings of the Rainwater and Urban Design Conference, 21-23 August. Sydney, Australia.

VAN ROON, M., GREENAWAY, A., DIXON, J. & EASON, C. (2006) Low impact urban design and development: scope, founding, principles and collaborative learning. 7th International Conference on Urban Drainage Modelling and 4th International Conference on Water Sensitive Urban Design. Melbourne, Australia.

VARMAN, M., CHATTERJEE, A. & ABUHAMMOUR, W. (2009) Enterococcal Infection. Emedicine, http://emedicine.medscape.com/article/971259-overview.
Accessed 12 December 2009

VASUDEVAN, P., TANDON, M., KRISHNAN, C. and THOMAS, T. (2001) Bacteriological quality of water in DRWH. 10th International Rainwater Catchment Systems Conference, Mannheim, Germany.

WARD, S., BUTLER, D. & MEMON, F. (2008) A pilot study into attitudes towards and perceptions of rainwater harvesting in the UK. 10th Symposium of the British Hydrological Society: Sustainable Hydrology for the 21st Century. Exeter, UK.

WARD, S., BUTLER, D., BARR, S. & MEMON, F. A. (2009) A framework for supporting rainwater harvesting in the UK. Water Science and Technology, 60 (10), 2629-2636.

WARD, S., MEMON, F. A. & BUTLER, D. (2010a) Harvested rainwater quality: the importance of appropriate design. Water Science and Technology, 61 (7), 1707-1714.

WARD, S., MEMON, F. A. & BUTLER, D. (2010b) Rainwater harvesting: model-based design evaluation. Water Science and Technology, 61 (1), 85-96.

WARREN, L. (2010) Risk of further flooding in UK as Xynthia approaches. The Independent. London.
http://www.independent.co.uk/news/uk/home-news/risk-of-further-flooding-in-uk-as-xynthia-approaches-1913791.html.
Accessed 01 March 2010

WATERS, D., EDGAR WATT, W., MARSALEK, J. & ANDERSON, B. C. (2003) Adaptation of a Storm Drainage System to Accommodate Increased Rainfall Resulting from Climate Change. *Journal of Environmental Planning and Management*, 46 (5), 755-770.

WATERWALL (2009) Waterwall rainwater tanks: Fatboy.
http://waterwalltanks.squarespace.com/raintank-gallery/waterwall-fatboy-tanks/1866382. Australia.
Accessed 15 August 2009

WATERWISE (2006) Consumption & Metering.
http://waterwise.sebenza-hosting.com/images/site/Documents/pcc%20and%20metering%20summary.pdf.
Accessed 12 June 2007

WATERWISE (2008) Evidence Base for Large-scale Water Efficiency in Homes. London, Waterwise, London.

WATERWISE (2009) Preston Water Efficiency Initiative.
http://www.waterwise.org.uk/images/site/Research/preston%20water%20efficiency%20initiative%20-%20final%20report%20-%20march%202009%20-%20waterwise%20with%20partners.pdf. Accessed 19 April 2009
WEB4WATER (2009) Price signals needed to encourage behaviour change.
http://www.web4water.com/news/news_story2.asp?id=4557.
Accessed 24 June 2009

WHEATLEY, A. D. & SURENDRAN, S. (2008) Greywater treatment and reuse results from a 50-person trial. *Urban Water*, 5 (3), 187-194.

WHERLOCK, J. (2009) Dwr Cymru Welsh Water Surface Water Management Strategy. Experiences with Rainwater Harvesting and Greywater Recycling and their Future Prospects. Aqua enviro, Birmingham, UK.

WHITE, I. (2007) Synthesis of a theoretical framework for understanding factors that catalyse and influence household adoption of rainwater harvesting. Proceedings of the 13th International Rainwater Catchment Systems Conference and 5th International Water Sensitive Urban Design Conference. Sydney, Australia.

WHITE, I. (2009) Decentralised Environmental Technology Adoption: The Household Experience with Rainwater Harvesting. Unpublished PhD Thesis, School of Environment Science, Environment, Engineering and Technology. Griffith University, Brisbane.

WHO (2006) Guidelines for the safe use of wastewater, excreta and greywater. (electronic version for the web)
http://www.who.int/water_sanitation_health/wastewater/gsuww/en/index.html
Accessed 12 December 2007

WHO (2008) Guidelines for Drinking-water Quality. (electronic version for the web)
http://www.who.int/water_sanitation_health/dwq/fulltext.pdf.
Accessed 18 January 2009

WHO (2009) Health Impact Assessment - Tools and Methods. (electronic version for the web)
http://www.who.int/hia/tools/en/.
Accessed 18 December 2009

WIKIPEDIA. (2007) Public water supply and sanitation in Germany.
http://en.wikipedia.org/wiki/Public_water_supply_and_sanitation_in_Germany
Accessed 27 May 2007

WILLIAMS, N. (2009) Water technology list retrofit enquiry. Personal Communication, Email. AEA Technology. 01 September 2009.

WPL (2007) Above and Below Ground Rainwater Harvesting Systems.,
http://www.ribaproductselector.com/document/pdf/11970/COL1211970/Rainwater-Harvesting-for-domestic-properties-commercial-buildings-and-school-premises.aspx.
Accessed 27 May 2007

WU, C., JUNQI, L., YAN, L. & WENHAI, W. (2003) First flush control for urban rainwater harvest systems. . Proceedings of 11th International Rainwater Catchment Systems Conference. August. Texcoco, Mexico.

YAGO, J. (2008) Car/truck Battery for Existing Well Pump.
http://backwoodshome.com/blogs/JeffYago/category/water/well-pump/.
Accessed 21 December 2008

YASHIMA, H. (2009) Efforts to install rainwater runoff control facilities in Fukuoka city. The 8th International Conference on Urban Drainage Modelling and the 2nd International Conference on Rainwater Harvesting and Management. 7-12th September. Tokyo, Japan.

YAZIZ, M., GUNTING, H., SAPIARI, N. & GHAZALI, A. (1989) Variation in rainwater quality from roof catchments. *Water Research*, 23 (6), 761-765.

YIN, R. K. (2003) Case Study Research: Design and Methods. Sage, London.

YOSHIOKA, K., OKADA, N. & MURASE, M. (2009) An analysis of the dissemination process of rainwater tanks in Japanese urban areas. The 8th International Conference on Urban Drainage Modelling and the 2nd International Conference on Rainwater Harvesting and Management. 7-12th September. Tokyo, Japan.

ZAIZEN, M., URAKAWA, T., MATSUMOTO, Y. & TAKAI, H. (1999) The collection of rainwater from dome stadiums in Japan. *Urban Water*, 1, 355-359.

ZHANG, D., GERSBERG, R. M., WILHELM, C. & VOIGT, M. (2009) Decentralized water management: rainwater harvesting and greywater reuse in an urban area of Beijing, China. *Urban Water*, 6 (5), 375-385.

ZOPPOU, C. (2001) Review of urban stormwater models. *Environmental Modelling and Software*, 16 (3), 195-231.

APPENDIX A

List of Publications

1. Potter, K., Macdonald, N., Ward, S., Shaw, D. and Butler, D. (Submitted) Engineers and Planners – the role of partnerships in pursuing sustainable water management objectives. For submission to the ICE journal *Engineering and Sustainability* and the 2010 British Hydrological Society Symposium

2. Ward, S., Barr, S., Memon, F. A. and Butler, D. (Accepted) Transitioning SMEs to sustainable water management practices: challenges and opportunities. Paper accepted to the International Conference on Sustainable Water Management (SWM2010), Jamshoro, Pakistan

3. Ward, S., Memon, F.A. and Butler, D. (2010) Harvested rainwater quality - the importance of appropriate design. *Water Science and Technology*, 61 (7), Pp 1707-1714

4. Ward, S., Memon, F.A. and Butler, D. (2010) Rainwater harvesting: model-based design evaluation. *Water Science and Technology*, 61 (1), Pp 85-96

5. Ward, S., Butler, D., Barr, S. and Memon, F.A. (2009) A framework for supporting rainwater harvesting in the UK. *Water Science and Technology*, 60 (10), Pp 2629-2636

6. Ward, S., Memon, F.A. and Butler, D. (2009) Harvested rainwater quality - the importance of building design. 2nd International Conference on Rainwater Harvesting and Management, Tokyo, September 2009

7. Ward, S., Butler, D., Barr, S. and Memon, F.A. (2009) A framework for supporting rainwater harvesting in the UK. 10th IWA UK National Young Water Professionals Conference, London, April 2009

8. Ward, S., Memon, F.A., Butler, D. (2008) Rainwater harvesting: model-based design evaluation. 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK, September 2008

9. Ward, S., Butler, D. and Memon, F.A. (2008). A pilot study into attitudes towards and perceptions of rainwater harvesting in the UK. 10th BHS National Hydrology Symposium, Exeter, September 2008

10. Ward, S. (2007) Rainwater Harvesting in the UK - Current Practice and Future Trends. Young Scientists Workshop, Amsterdam, Netherlands, April 2007

APPENDIX B FOR CHAPTER 3

(Understanding Stakeholder Receptivity – Householders, Office Tenants and Architects)

Contents

School of Engineering, Computing and Mathematics
Ethical Issues: Approval of Project Proposal

Please complete and submit this form and the attached documents to the Learning and Teaching Office. The Schools Ethics Officer and the appropriate Programme Coordinator will consider your proposal. You will be informed in writing of the outcome.

Name of Student: Sarah Ward
Name of Supervisor: Professor David Butler
Project Title: An operational framework to enhance the implementation of rainwater harvesting

Indicate which of the following areas of concern are relevant to the project:

a) Involvement of members of the University in investigations	
b) Involvement of members of the public, in particular children, in investigations	X
c) Involvement of external organisations where this may be contentious or affect the reputation of the University	X*
d) Investigations which require access to personal data	X

X* ***although the research will involve the use of external organisations, this should not be contentious or affect the reputation of the University (as aforementioned organisations will be volunteering to take part).***

Attach to this form, as appropriate, the following documents:

a) A project proposal indicating clearly where ethical issues arise (mandatory)	X
b) A protocol for the involvement of members of the University or members of the public (e.g. details of the use of interviews, observations, experiments)	X
c) A statement of the involvement of external organisations	X
d) A protocol for the collection of personal data	X
e) A statement of the intended use and possible retention of any data collected in (b) or (c) or (d)	X

Signature of Student	S Ward	**Date** **08/01/09**
Signature of Supervisor	D Butler	**Date** 14/1/09

For Office use only

	Signature	**Date**
a) Form received		
b) Proposal approved by Programme Coordinator		
c) Proposal approved by Ethics Officer	M Berg	14/1/09
d) Certificate of Approval issued		

a) Project Proposal (indicating where the ethical issues arise):

Proposal:

Use of a bottom-up approach to develop an operational framework to enhance the willingness and ability of a range of Class A & B stakeholders to implement rainwater harvesting (RWH).

The research will aim to:

1) Provide a **technical evidence base** on RWH in UK (monitoring activities - efficiency/savings data; rainwater quality data; non-domestic demand profiling);

2) Provide a **stakeholder insight evidence base** on RWH in UK (questionnaires, interviews, case studies; with architects, system users/non-users (public, schools and small to medium enterprises (SMEs));

3) Assessment of current willingness and ability and how to improve this, as well as **identification of 'problem areas'** for each stakeholder group;

4) Provide a **set of core guidelines** to address these 'problem areas' for each stakeholder group (**including process maps** which identify all parties/expectations/resources/requirements/decisions involved in implementing RWH).

Ethical issues arise in item (2) and will include:

i. Use of questionnaires (as part of a survey) with members of the public;
ii. Potential follow-up interviews with volunteers (members of the public);
iii. Exploratory interviews with local business owners, architects and school staff (no children).

b) A protocol for the involvement of members of the University or members of the public, c) A statement of the involvement of external organisations and d) A protocol for the collection of personal data:

Standard questionnaire/survey/interview techniques will be used (Dilman, 1978; Oppenheim, 2005). Postal and online questionnaires will be administered to householders from two case study sites. Both versions will have the appropriate confidentiality/data protection information at the beginning. Potential follow-up interviews will only be made with those questionnaire participants that volunteer when asked at the end of the questionnaire and whom provide their contact details for future research. Contact details will not be collected as part of the questionnaire, unless volunteered by the participants. Online questionnaires will also be submitted to a range of architectural firms, as well as selected local business, who will have been contacted using a database provided by Global Action Plan, (http://www.globalactionplan.org.uk/index.aspx).

Exploratory interviews will be conducted with the above organisations, again on a voluntary basis via the questionnaire. Exploratory interviews/meetings will also be conducted with school staff, which have either previously contacted the researcher, or with whom the researcher has contacted and confirmed that interviewing will be possible.

Personal data collected will include the usual demographic parameters of any questionnaire/survey, such as age, gender and occupation, as well as a limited number of specific items related to the research, such as ‘Do you have a garden’, ‘Do you own or rent your home’ and ‘How many people usually live in your home’.

e) A statement of the intended use and possible retention of any data collected in (a) and (b):

Personal data will only be used to identify statistical trends/differences between demographic groups. Such data will be retained confidentially in two ways. Firstly, paper-based documents will be stored within an unmarked folder, which will be locked within an under-desk cabinet, to which only the researcher has the key (and located within a locked office within the Harrison Building). Secondly, electronic data will be kept within a password-protected database document, which will be stored on a password-protected PC (again located within a locked office within the Harrison Building).

References:

Dillman, D. A (1978) *Mail and Telephone Surveys*. Wiley-Interscience, Chichester;

Oppenheim, A. N. (2005) *Questionnaire Design, Interviewing and Attitude Measurement*. Continuum, London.

Broadclose

School of Engineering, Computing and Mathematics

Sarah Ward
Harrison Building
North Park Road
Exeter
EX4 4QF

Telephone +44 (0)1392 263600

Email sw278@exeter.ac.uk
Web www.exeter.ac.uk

13-11-2008

Dear Resident,

I am a researcher at the University of Exeter undertaking a research project into alternative water resources, in particular rainwater harvesting systems (a water-saving technology). Your household has been asked to participate as it uses a rainwater harvesting system. We are very interested to know about your opinions and experiences in relation to the system. The questionnaire is anonymous in that we will not know or ask for personal details like your name. However, we will ask questions on some personal things, like age and what you do for a living. This will help with our analyses and enable us to provide better information for different groups in the future.

Please find enclosed a paper copy of the questionnaire. However, if you would prefer to complete the questionnaire using the internet a website address and login details are provided on page 2 of the questionnaire. Whichever version you decided to complete, it should take around 15 minutes.

If you complete the paper-based version, please return it to us as soon as possible in the stamped, addressed envelope provided (if you misplace this envelope, call us on 01395 263600 and we will send out another).

This questionnaire will provide us with valuable information on a range of topics, with which we hope to provide better information on alternative water resources in the future. We would like to thank you in advance for your time and hope you will be able to complete the questionnaire.

Yours sincerely

Sarah Ward
PhD researcher (sw278@exeter.ac.uk)

Enclosed:
1 paper copy of the questionnaire
1 stamped, addressed envelope

Littleham

UNIVERSITY OF EXETER
Centre for Water Systems

School of Engineering, Computing and Mathematics

Sarah Ward
Harrison Building
North Park Road
Exeter
EX4 4QF

Telephone +44 (0)1392 263600

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13-11-2008

Dear Resident,

I am a researcher at the University of Exeter undertaking a research project into alternative water resources, in particular rainwater harvesting systems (a water-saving technology). We are writing to ask if you would take part in a questionnaire, as we would be very interested to know about your opinions in relation to such systems. The questionnaire is anonymous in that we will not know or ask for personal details like your name. However, we will ask questions on some personal things, like age and what you do for a living. This will help with our analyses and enable us to provide better information for different groups in the future.

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Harrison Building
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Web

02-02-2009

Dear Resident,

During November last year (2008), we wrote to you asking for your participation in a questionnaire about alternative water resources. Although we have had a good response so far, we are writing to ask you to send us your completed questionnaire if you have not yet completed or returned it. If you have returned it, we would like to thank you sincerely for your time and effort.

The extent to which we will be able to describe accurately householder's feelings and perceptions is determined by the response to this questionnaire. We would therefore ask, if you have not already completed it, to complete it and return it as soon as you can.

If you no longer have a copy of the questionnaire, there are two ways you can obtain it:

1) Call 07720771915 (this call will cost just 12p) and leave your surname and the first line of your address and we will post you a copy, along with a stamped envelope for you to return it to us. Your details will only be used to send you the questionnaire;

2) Go online (the internet) and use the following details:

    - Go to this secure website: http://apart.ex.ac.uk/Login
    - Enter this Login code: EAC9-E4C3
    - Enter this Password: password

This is the first questionnaire entirely dedicated to finding out what householders think of rainwater harvesting and therefore the results are incredibly valuable to a number of organisations, such as water companies, system manufacturers and the Government. It is for this reason that we have delivered this follow-up letter.

This questionnaire will provide us with valuable information on a range of topics, with which we hope to provide better information on alternative water resources in the future. As such, your contribution to the success of this study will be greatly appreciated.

Yours sincerely

Sarah Ward
PhD researcher (sw278@exeter.ac.uk)

Broadclose

UNIVERSITY OF EXETER
Centre for Water Systems

School of Engineering, Computing and Mathematics

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Yours sincerely

Sarah Ward
PhD researcher (sw278@exeter.ac.uk)

Broadclose

School of Engineering, Computing and Mathematics

Sarah Ward
Harrison Building
North Park Road
Exeter
EX4 4QF

Telephone +44 (0)1392 26

Email sw278@exeter.ac.uk
Web www.exeter.ac.uk

Dear

During late 2008 we wrote to you with a questionnaire on alternative water resources – which you kindly completed and returned to us. When filling out the questionnaire you ticked the 'feedback' box and provided us with your contact details.

Please find enclosed some results from the overall survey – we had a very good response and are now using the information gathered within our research. A copy of these results has also been sent to The Guinness Trust, so that they can see how rainwater harvesting is being received and how things are operating at Broadclose.

We would like to thank you once again for returning your completed questionnaire and helping us with our research.

Yours sincerely

Sarah Ward
PhD researcher (sw278@exeter.ac.uk)

A selection of results from the survey on alternative water resources

A lot of data was collected during the survey and it was very difficult to decide what to include within this feedback summary (if we had included everything this document would be a very large!). However, we decided to pull out those results which we thought would be the most relevant to you, as a resident of Broadclose. We hope you find the following summaries, tables and figures interesting; the information is broken down by topic.

Water conservation

The first noteworthy item was the value placed on water conservation at Broadclose. It was very encouraging to note that to the question '*Do you value water conservation?*' no one answered '*no*' – even if a few participants were slightly '*unsure*'! The results are summarised in Table 1.

Table 1: Participants responses to the question: '*Do you value water conservation?*'

Yes	97%
Unsure	3%

The main reasons given for valuing water conservation included being able to save money on water bills, as well as a real enthusiasm for helping the environment and a desire to prevent wastage of natural resources.

Places to access information on rainwater harvesting (RWH)

The responses to this question were quite surprising. Unexpectedly no one answered that a DIY store would be a useful place to obtain information. By far the most popular answer was *'with my water bill'*, which will help us to consider how the water companies could help with the promotion of alternative water resources. A summary of the results is illustrated in Figure 1.

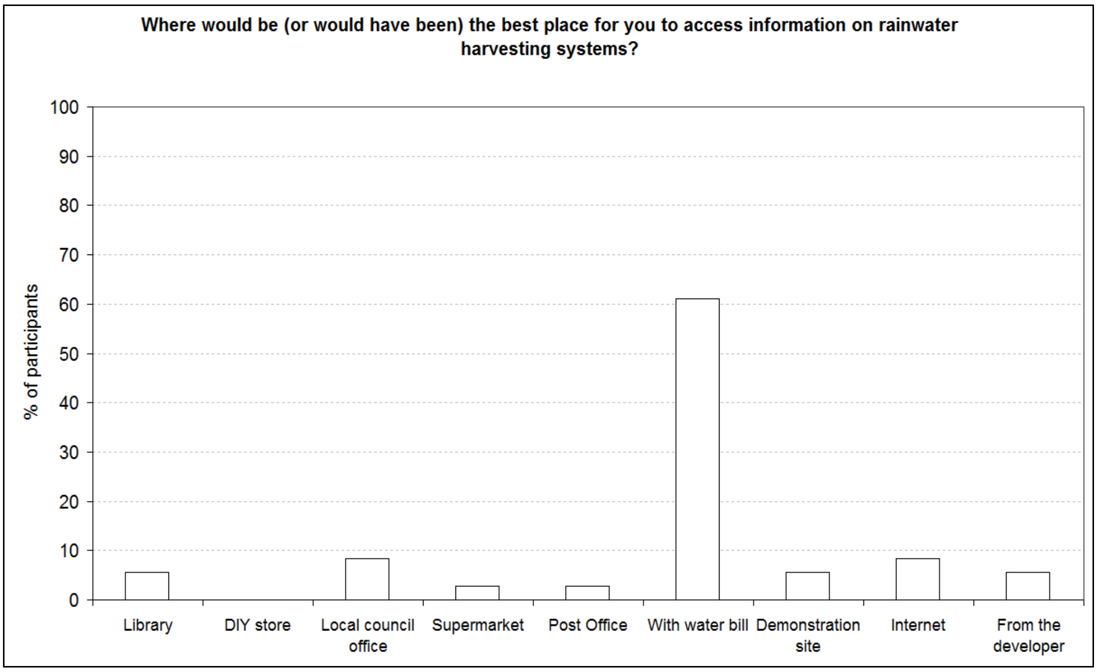

Figure 1: Most suitable place to obtain information on RWH

Two answers given that were not in the original list were the '*internet*' and '*from the developer*'; again interesting responses. This indicated to us that perhaps the developer may need to play a greater role in providing information about the RWH systems present in a development.

Factors encouraging and discouraging consideration of RWH

Overwhelmingly, half of all those that took part in the survey indicated that if they could save money on their water bills, they would consider installing a RWH system (Figure 2). The second most popular response was '*if I was given a grant*', which could have important implications for Government policy; it is currently not planning to introduce a subsidy scheme for domestic RWH, similar to that available for businesses.

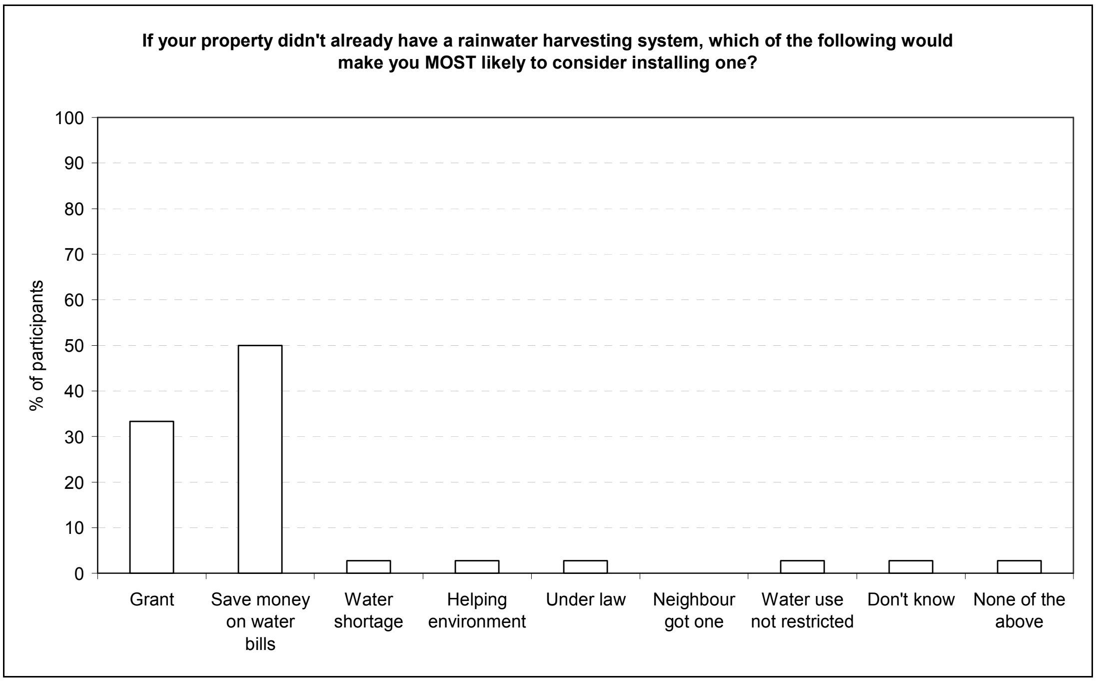

Figure 2: Factors most likely to make people consider installing a RWH system

Although helping the environment received a very low percentage of the responses in this question, it ranked as the top response when a list of factors which might encourage people to consider install a RWH system was presented. The top three responses from the list of eighteen are summarised in Table 2.

Table 2: Top 3 factors which might encourage consideration of installing a RWHS

1st	**Helping the environment**
2nd	**Saving money on water bills**
3rd	**Helping to reduce the amount of high quality tap water used for non-drinking purposes**

As anticipated the top two factors which would most *discourage* people from considering installation of a RWH system were: 1) having to pay for regular maintenance and 2) the disruption caused to the home and life during installation.

Toilet performance and satisfaction

When asked about the performance of the toilet flushed using the RWH system, a number of interesting points became apparent. Firstly, similar levels of people experienced differences with the cleaning performance, the flush performance, the noise made by the toilet and the odour coming from the toilet/water (Figure 3). A minority of people commented that the cleaning ability and the pressure of the toilet were reduced and that sometimes a lot of air freshener/cleaner was required to mask odours. A single incident of a '*very noisy*' toilet was reported. Unfortunately without fully examining both the toilets, fixtures and communal RWH systems concerned, it is very difficult to pinpoint the exact cause of these performance issues.

Interestingly, a third of participants experienced differences in the water colour and the toilet pan colour – with several commenting that the toilet pan had become stained. Some participants also noted that the water colour was most noticeably different after heavy rain, with words such as '*darker*', '*cloudy*' and '*funny*' being used to describe the colour difference. Such effects are regrettable but normal, as rainwater can contain some particulate matter, which adheres to the toilet pan or can become suspended into the water when it is piped into the pan.

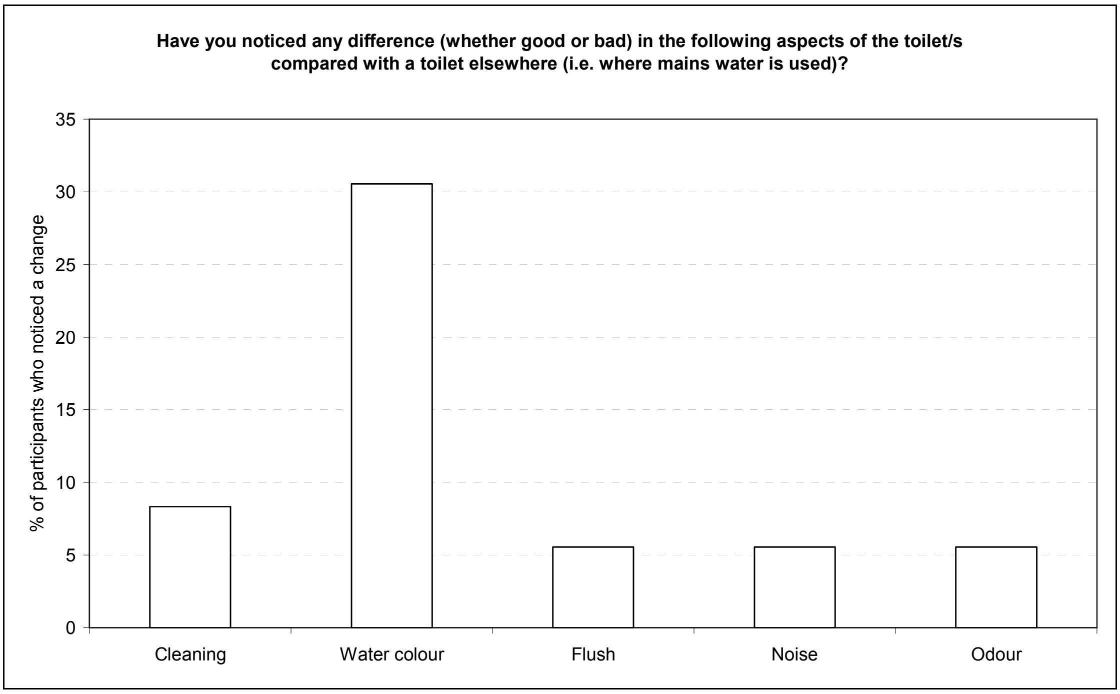

Figure 3: Differences noticed in aspects of toilet performance at Broadclose

Although these differences were noted and commented on, when asked how they felt about them the majority of people responded with '*not bothered*'. Additionally, a total of 94% of people responded as being either '*very satisfied*' or '*satisfied*' with the overall performance of the toilet (Figure 4, over the page).

Furthermore, three quarters (75%) of people were happy to recommend RWH systems to others (Table 3).

Table 3: Participants responses to the question: '*Would you recommend a RWH system to others?*'

Yes	75%
No	3%
Maybe	17%
Unsure	6%

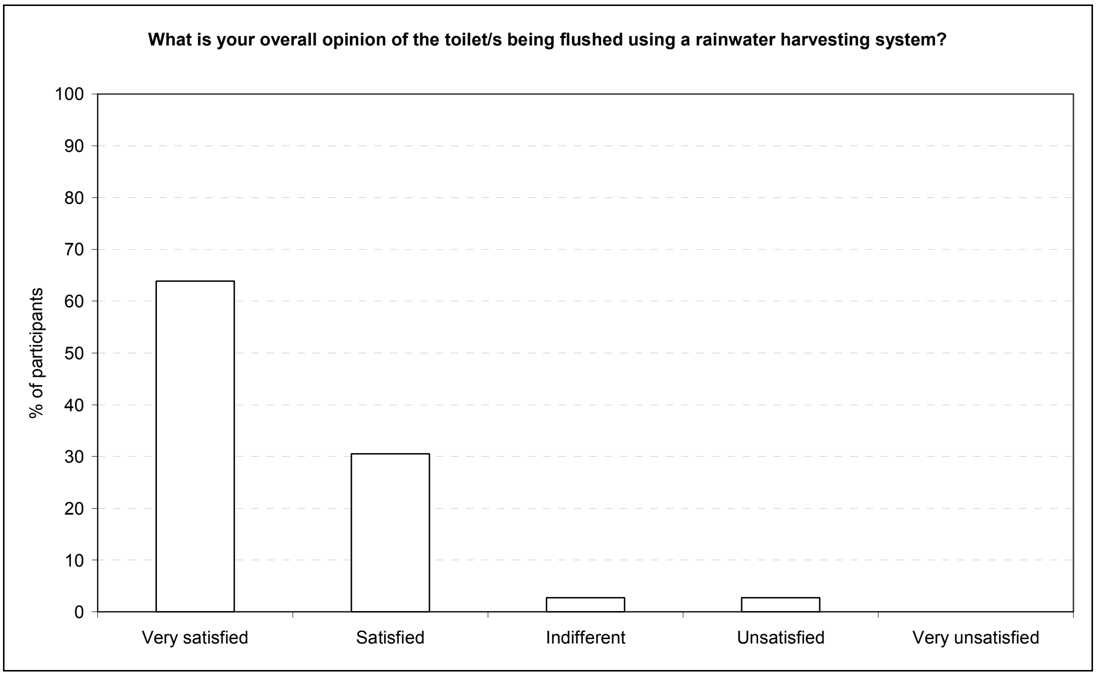

Figure 4: Overall satisfaction with toilet performance at Broadclose

Maintenance issues

From a research perspective data on people's perceptions of RWH system maintenance is very valuable. Previous research has shown that maintenance issues and costs are perceived as one of the main barriers to the uptake of RWH systems. However, the results of this survey were encouraging. Firstly, over 70% of participants recognised that performing routine maintenance of the RWH system was important (Table 4).

Table 4: Perceptions of the importance of RWH system maintenance

Yes	72%
No	/
Maybe	17%
Unsure	11%

Responses were also encouraging with respect to the cost of maintenance (Figure 5, over the page). Over three quarters (81%) of participants responded that they thought the cost of four maintenance activities (cleaning the catchment; cleaning filters; replacing UV lamp; checking the pump) were up to £300. The actual average cost would be around £250 for an annual contract, thus perceptions were generally inline with reality. The amount people would be willing to pay however, was somewhat different, with most people preferring to pay less than £100. This amount would be most realistic to achieve in developments where communal RWH systems are installed (such as at Broadclose), as the cost is shared by all the residents. This information may help to determine how best to promote the installation of domestic RWH systems.

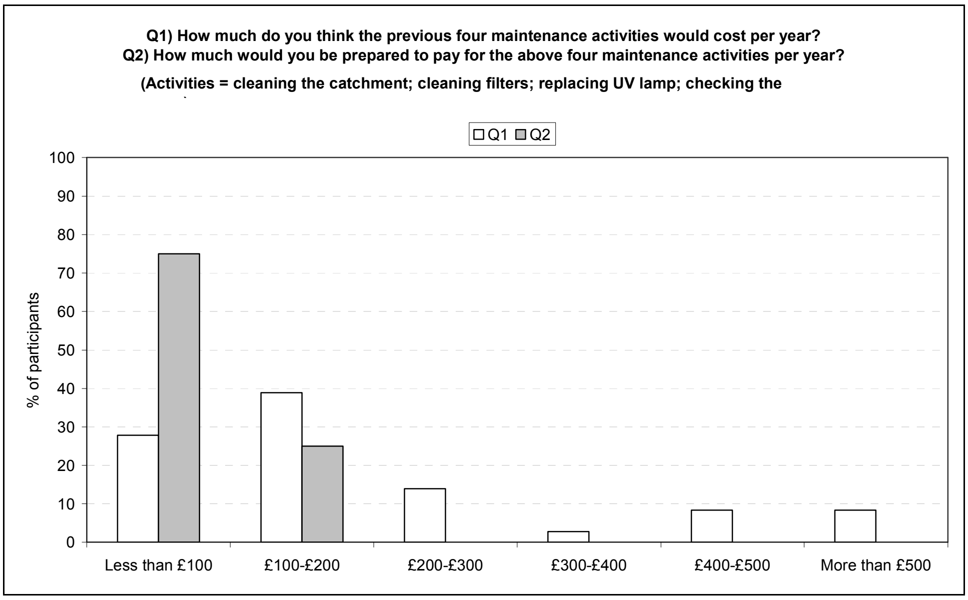

Figure 5: Estimated costs and acceptable level of costs for maintenance activities

Unfortunately when it came to knowing who was responsible for maintaining the RWH systems, participants were slightly less informed. As can be seen from Table 5, the majority of people (56%) answered '*don't know*' to the question '*Who is responsible for maintaining the rainwater harvesting system in this property?*'. Although at first this may seem disappointing, it is very useful information – it will help determine how to inform residents in developments with communal RWH systems about maintenance provision; something which was clearly neglected at Broadclose. Currently maintenance at Broadclose is performed by a maintenance management company set up by The Guinness Trust, North Cornwall Housing Association and Midas Homes (the developer).

Table 5: Perceptions of maintenance responsibility at Broadclose

Household member	/
Landlord	19
RWH supplier/maintenance company	22%
Other	3%
Don't know	56%

Using RWH for outdoor uses

One final interesting result was that more than 70% of people answered '*yes*' to the question '*Do you wish you could use the rainwater harvesting system for outdoor uses too?*'. The RWH systems at Broadclose only supply the toilets. However, dual-purpose systems are available, which would provide an outside tap supplied by rainwater. This result is useful for indicating to housing developers that it is important to consider the type of system to install during the design phase of a development. Where rainfall is high enough and catchment (roof) sizes are suitable it may be more useful to install dual-purpose systems, than household-only systems – this would potentially help conserve more water/money.

We hope that this information has been interesting for you to read. We also hope that you can see how the information you have provided will be used, for example by helping to provide recommendations to industry and Government.

Littleham

UNIVERSITY OF EXETER
Centre for Water Systems

School of Engineering, Computing and Mathematics

Sarah Ward
Harrison Building
North Park Road
Exeter
EX4 4QF

Telephone +44 (0)1392 26

Email sw278@exeter.ac.uk
Web www.exeter.ac.uk

Dear

During late 2008 we wrote to you with a questionnaire on alternative water resources – which you kindly completed and returned to us. When filling out the questionnaire you ticked the 'feedback' box and provided us with your contact details.

Please find enclosed some results from the overall survey – we had a very good response and are now using the information gathered within our research.

We would like to thank you once again for returning your completed questionnaire and helping us with our research.

Yours sincerely

Sarah Ward
PhD researcher (sw278@exeter.ac.uk)

A selection of results from the survey on alternative water resources

A lot of data was collected during the survey and it was very difficult to decide what to include within this feedback summary (if we had included everything this document would be a very large!). However, we decided to pull out those results which we thought would be the most relevant to you, as a resident of the Littleham Estate. We hope you find the following summaries, tables and figures interesting; the information is broken down by topic.

Water conservation

The first noteworthy item was the value placed on water conservation at Littleham. It was very encouraging to note that to the question '*Do you value water conservation?*' no one answered '*no*' – even though a few participants answered '*maybe*'. The results are summarised in Table 1.

Table 1: Participants responses to the question: '*Do you value water conservation?*'

Yes	91%
Maybe	9%

The main reasons given for valuing water conservation included being able to save money on water bills (many people reported they had a meter fitted), as well as a real enthusiasm for helping the environment and a desire to prevent wastage of natural resources.

Alternative water resources

Several general questions were asked about alternative water resources – for example; '*Have you ever used a rainwater harvesting system?*'. Responses to this question revealed that a very small minority (9%) had used a RWH, with one report of it being used abroad. Despite this low amount of previous experience, it was revealed that 70% of participants would be happy to flush a toilet with water from a source other than from a mains supply.

In terms of the type of alternative water resource used to flush a toilet (such as rainwater harvesting or grey water reuse), the results were quite interesting and are summarised in Figure 1 (over the page).

As can be seen in Figure 1, the most acceptable source was rainwater from people's own house roofs, with 87% of participants responding '*yes*' to considering this source. The second most acceptable source was rainwater from neighbouring houses (52%), closely followed by grey water from people's own houses (48%). The use of grey water from neighbouring houses was, perhaps unsurprisingly, the least popular, with less than a fifth (17%) of participants happy to consider it. This is very useful information, as it could help housing developers with decisions on which types of alternative water resource to consider implementing in new housing developments. For example, there are already several developments where communal RWH systems have been installed – rainwater is collected from the roofs of several different houses, stored in one communal underground storage tank and then supplied back into the houses whose roofs were used.

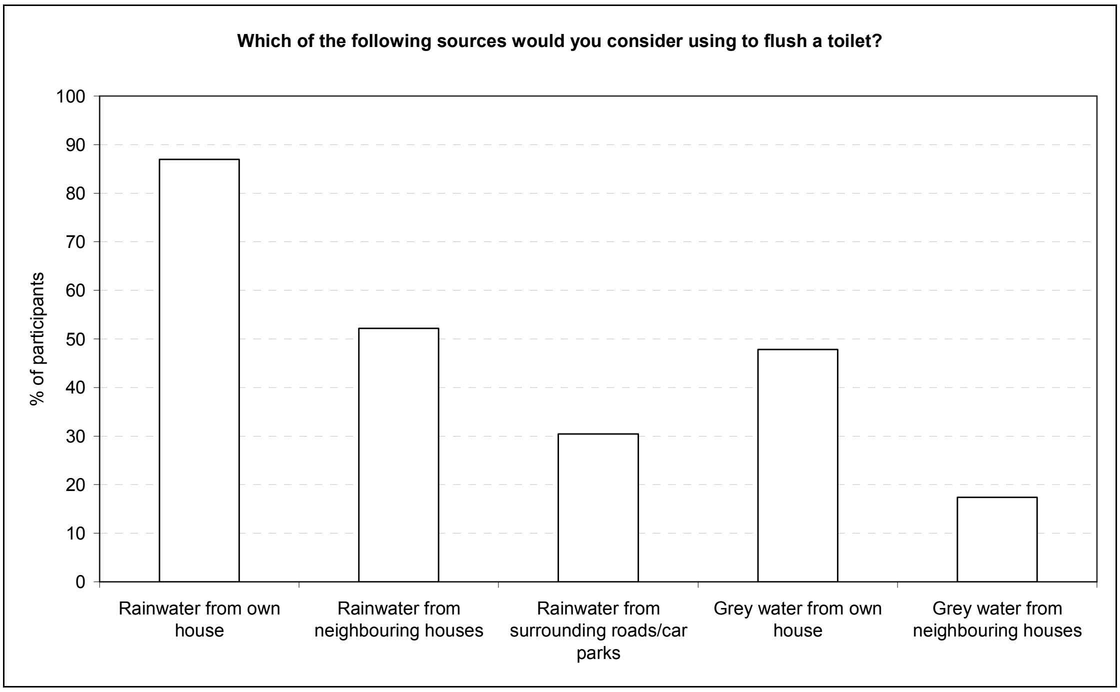

Figure 1: Willingness to use different alternative water resources to flush a toilet

Places to access information on RWH

The responses to this question were quite surprising. The joint second most popular places were '*my local library*' and the '*internet*'. However, by far the most popular answer was *'with my water bill'*, which will help us to consider how the water companies could help with the promotion of alternative water resources. A summary of the results is illustrated in Figure 2.

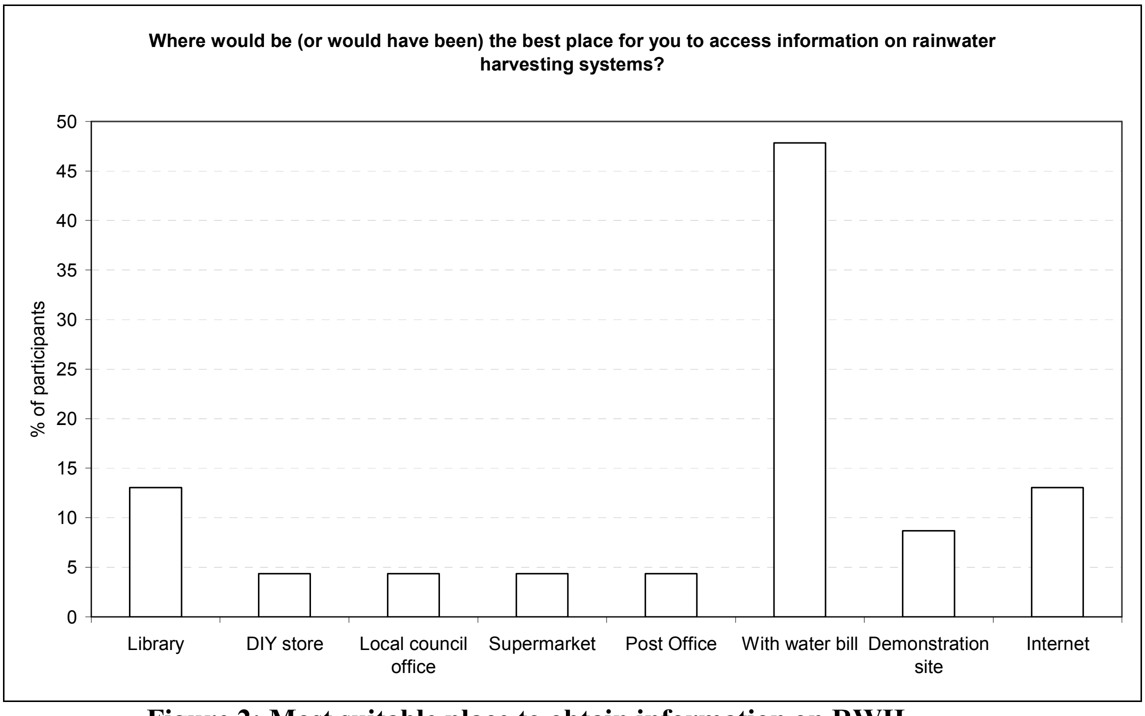

Figure 2: Most suitable place to obtain information on RWH

Factors encouraging and discouraging consideration of RWH

Just under a quarter (22%) of people responded that if they could save money on their water bills, they would consider installing a RWH system (Figure 3). However, the most popular response was '*if I was given a grant*' (43%). This could have important implications for Government policy; it is currently not planning to introduce a subsidy scheme for domestic RWH, similar to that available for businesses.

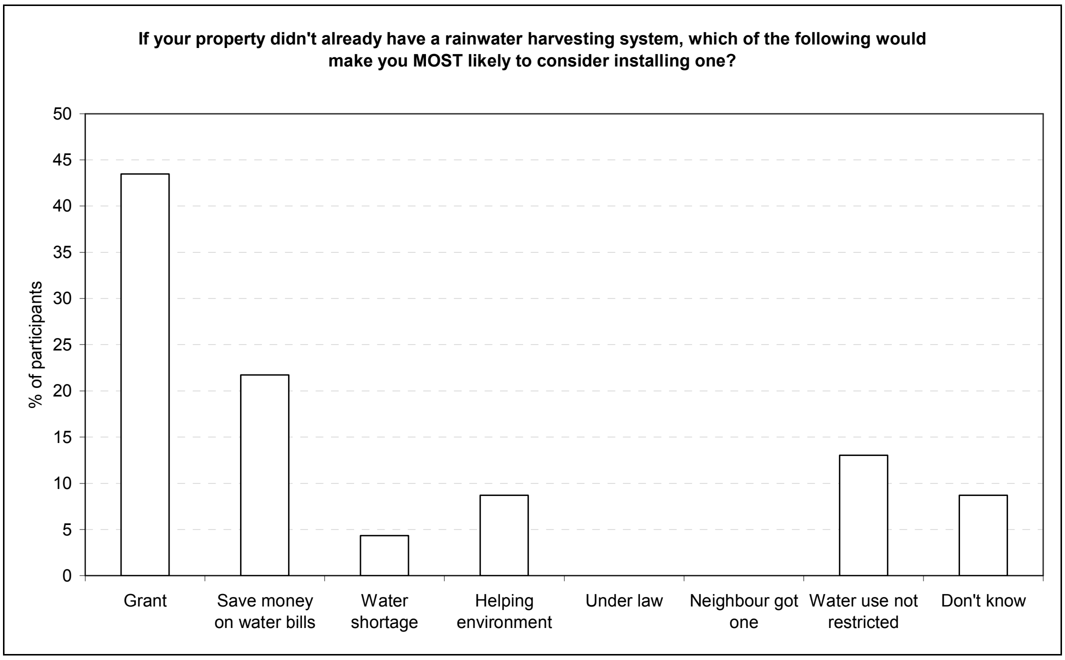

Figure 3: Factors most likely to make people consider installing a RWH system

Although helping the environment received a low percentage of the responses in this question, it ranked as joint second in the top four responses when a list of factors which might encourage people to consider install a RWH system was presented. The top four responses from the list of eighteen are summarised in Table 2.

Table 2: Top four factors which might encourage consideration of installing a RWHS

1st	Saving money on water bills
2nd	Installation subsidies/grants
	Helping the environment
3rd	Helping to reduce the amount of high quality tap water used for non-drinking purposes

As anticipated the top two factors which would most *discourage* people from considering installation of a RWH system were: 1) having to pay for regular maintenance and 2) the disruption caused to the home and life during installation.

Maintenance issues

From a research perspective, data on people's perceptions of RWH system maintenance is very valuable. Previous research has shown that maintenance issues and costs are perceived as one of the main barriers to the uptake of RWH systems. Within this survey over three quarters (78%) of participants recognised that performing routine maintenance of the RWH system was important (Table 3).

Table 3: Perceptions of the importance of RWH system maintenance

Yes	78%
No	/
Maybe	13%
Unsure	9%

However, when it came to estimating the cost of maintenance there was quite a spread in responses (Figure 4). Just under half (48%) of participants responded that they thought the cost of four maintenance activities (cleaning the catchment; cleaning filters; replacing UV lamp; checking the pump) would be less than £100 and 65% thought it would be £300 or less. The actual average cost would be around £250 for an annual contract, thus perceptions of cost were generally slightly lower than reality. With regards to the amount people would be willing to pay, over 80% of participants would only be willing to pay £100 or less. This amount would be most realistic to achieve in developments where communal RWH systems are installed, as the total annual cost would be shared between all the residents. This information may help to determine how best to promote the installation of domestic RWH systems.

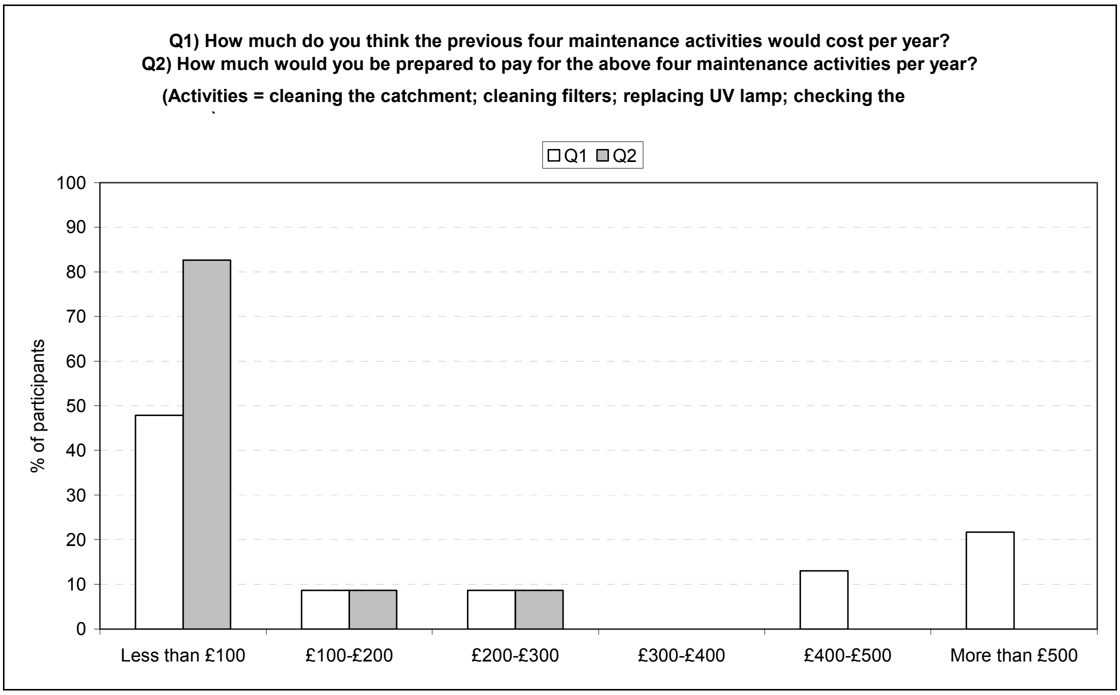

Figure 4: Estimated costs and acceptable level of costs for maintenance activities

We hope that this information has been interesting for you to read. We also hope that you can see how the information you have provided will be used, for example by helping to provide recommendations to industry and Government.

Broadclose

School of Engineering, Computing and Mathematics

Sarah Ward
Harrison Building
North Park Road
Exeter
EX4 4QF

Telephone +44 (0)1392 263600

Email sw278@exeter.ac.uk
Web www.exeter.ac.uk

Dear Mr X,

You recently kindly completed our online questionnaire about alternative water resources, including rainwater harvesting.

On the final page of the questionnaire was an option box asking if you would like to participate in future research on alternative water resources. You kindly ticked this box. We are now conducting questionnaire follow-up interviews (the final stage of the research) with a small number of people and would like to ask you to participate, if possible.

The interview would last approximately an hour and can be arranged at a time convenient for you.

If you are happy to participate, please provide us with the details outlined on the slip below. We will contact you shortly after receiving your reply, in order to finalise a date and time. We are happy to come to your home, if this is acceptable to you, or are happy to conduct the interview in a different location if this is something you would prefer. If you do not wish to participate, we would like to thank you for your time and would be very grateful if you could tick 'No' on the slip below and return it to us.

We would like to take this opportunity to thank you once again for completing the questionnaire and hope you will agree to participate in an interview.

Yours sincerely

Sarah Ward
PhD researcher (sw278@exeter.ac.uk)

Please cut/tear off this slip and return it in the stamped, addressed envelope provided

I would like to participate in a questionnaire follow-up interview: Yes ☐ No ☐

I can be contacted on this number, to finalise arrangements: ____________________

(Your number will not be used for anything other than to contact you to arrange the interview and will be stored confidentially).
The best days/times of day for me are: **please tick the box next to the appropriate day/time**
Note: am = starting between 10am and 12pm; pm = starting between 1pm and 6.30pm; eve = starting between 6.30pm and 8pm (we would start the interview at 8pm at the latest, to finish at around 9pm).

	am	pm	eve		am	pm	eve		am	pm	eve
Monday				Tuesday				Wednesday			
Thursday				Friday				Sunday			

I am happy for the interview to be conducted in my home: Yes ☐ No ☐

I would prefer the interview to be conducted elsewhere: Yes ☐ No ☐

(This will be the café in your local Morrisons Supermarket on Stucley Road)

Broadclose 13/07/09

Littleham

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	am	pm	eve		am	pm	eve		am	pm	eve
Monday				Tuesday				Wednesday			
Thursday				Friday				Sunday			

I am happy for the interview to be conducted in my home: Yes ☐ No ☐

I would prefer the interview to be conducted elsewhere: Yes ☐ No ☐

(This would be a local community centre, to be confirmed)

Littleham 13/07/09

Questionnaire Follow-up Interview Greeting and Schedule

Good Evening

Could I speak to X

My name is Sarah Ward and I am a researcher at the University of Exeter.

You/X recently agreed to participate in a follow-up interview to a questionnaire on water use and rainwater harvesting you/X completed.

I am calling to conduct the interview – is it a convenient time for you/X.

If yes, proceed – if no, ask when would be convenient to call back.

I have five topic areas I would like to chat about, which should take about 20 minutes, if that sounds ok?

- Do you think it is important that RWH is promoted and used within the UK?

- What are your views on how RWH is being promoted within the UK?

- How do you think things could be improved/what do you think could be changed?

- Do you think the questionnaire helped you to think more about RWH (and water use in general)?

- Have you done anything differently since completing it?

University of Exeter

Alternative Water Resources

Gauging your opinions and experiences

A study by the Centre for Water Systems
At the University of Exeter

Welcome!

This is a questionnaire about alternative water resources, focusing on rainwater harvesting. Rainwater harvesting is a water-saving technology: rainwater is collected from roofs, stored in a tank and then reused within buildings - see page 3 for a diagram of an example system. This research aims to provide us with data which will allow the provision of better information regarding rainwater harvesting systems. The results are very important to a wide range of organisations.

We hope you can help us by completing this questionnaire. We would ask that the person who pays the water bill (or another adult) completes the questionnaire. Please try to answer all of the questions and as fully as possible. This will help the research to be as detailed as possible and will allow us to make a better interpretation of the results. **Please put a tick next to your choice of answer for each question.**

By completing this questionnaire you are giving consent for your responses to be used, confidentially, as part of this research project. The data you provide in this questionnaire will remain strictly confidential and it will not be possible to identify you or your household from the responses you provide.

Once you have completed the questionnaire, please return it in the stamped, addressed envelope provided.

If you would prefer, you can complete the questionnaire using the internet - please use the following details:

Go to this secure website:	**http://apart.ex.ac.uk/Login**
Enter this Log in code:	**EAC9-E4C3**
Enter this Password:	**password**

If you do complete the questionnaire online, please recycle the paper questionnaire.

If you require any further information about this questionnaire, please do not hesitate to get in touch. Your contact is:

Sarah Ward
Telephone: 01392 263600
Email: sw278@exeter.ac.uk

http://centres.exeter.ac.uk/cws/

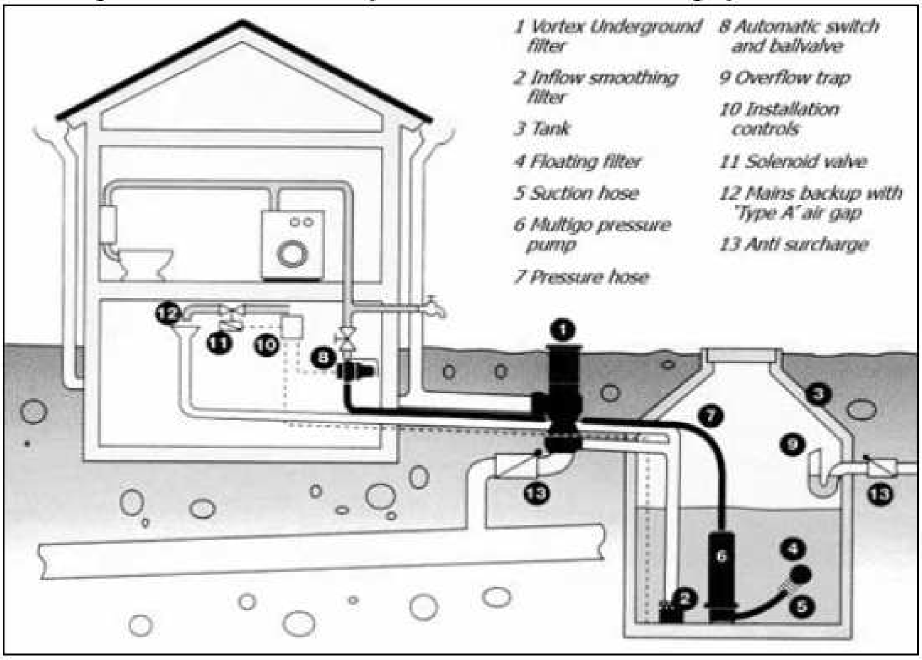
Centre for Water Systems
University of Exeter
Harrison Building
North Park Road
Exeter
Devon
EX4 4QF

A broad definition of rainwater harvesting is:

"rainwater falling on roofs is collected via guttering and downpipes and stored in a tank (usually underground), which is then used within a building - for example for flushing toilets".

Please note, a water butt collects rainwater, but is not a rainwater harvesting system: the rainwater is not piped into a building for use.

This diagram shows the basic layout of a rainwater harvesting system:



Q1
How useful was this diagram in helping you to understand what rainwater harvesting is?

Very useful	Useful	Neutral	Not very useful	Not at all useful

If you would like more information about rainwater harvesting systems, please contact us or visit the UK Rainwater Harvesting Association website (http://www.ukrha.org).

Q2
Where is the rainwater harvesting system to which you have access?
Please tick one.

In a home	In a place of work	Both

Other, please specify:

Q3
How long have you had access to this particular rainwater harvesting system?

Less than 1 month	
Between 1 and 3 months	
Between 3 and 6 months	
Between 6 and 12 months	
Between 1 and 5 years	
Over 5 years	
I am just visiting	

Please tick one and provide any additional information you'd like us to know about the rainwater harvesting system in the space provided.

Q4
Did you choose to live/work in the property which has the rainwater harvesting system?

Yes	No	Maybe	Unsure

Q5
Did the fact the property already had a rainwater harvesting system encourage you to buy/rent it?

Yes	No	Maybe	Unsure

If you answered yes or no, please give a reason (if possible)

Q6
If a property already had a rainwater harvesting system, would you be more likely to buy/rent it?

Yes	No	Maybe	Unsure

If you answered yes or no, please give a reason (if possible)

Q7
Have you ever obtained information about rainwater harvesting? If so, when?
Please choose one answer.

Before buying/renting/working/living in the property	
After buying/renting/working/living in the property	
I did not obtain any information at any time	

Please give details:

Q8
Where would be (or would have been) **the BEST place** for you to access information (for example a leaflet) on rainwater harvesting? **Please only TICK ONE.**

In my local library	
In my local DIY store	
In my local council office	
In my local supermarket	
In my local post office	
With my water bill	
At a demonstation site	
None of the above	
Other, please specify:	

Q9
How easy do you think rainwater harvesting technologies are to use?

Very easy	Easy	Neutral	Difficult	Very difficult

Q10
Do you think rainwater harvesting is a good thing?

Yes	No	Maybe	Unsure

Q11
Do you consider yourself to be environmentally conscious?

Yes	No	Maybe	Unsure

Q12
Do you value water conservation?

Yes	No	Maybe	Unsure

If possible please give a reason for your answer, for example: 'I value water conservation as it.... helps me save money....prevents wasting natural resources...' or 'I don't value water conservation as....I am too busy....I am not on a meter....' etc.

Q13

Have you used any of the following water saving devices and if so, how were your experiences with them?

Please put a tick next to one answer per table.

Hippo (or other 'save-a-flush' device) (a device that is put in the toilet cistern; the use of bricks has been known)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Dual flush toilet (a toilet that does a small flush and a large flush)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Slim line toilet (has a smaller cistern, which can also be dual flush)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Other non-standard toilet

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Aerator taps (taps which inject air into the stream of water, making it more bubbly)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Shower head flow restrictor (a device fitted inside the shower head)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Water meter (fitted by a relevant Water Company to the incoming water main)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Water butt (simple plastic storage tanks for the garden)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Rainwater harvesting system (storage tank for uses such as toilet flushing, not to be confused with a water butt)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Greywater system of any kind (greywater is water that has been used once and is then stored, treated and reused for purposes such as toilet flushing)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Any others, please specify:	

Q14

Would you be happy to flush a toilet with water from a source other than the mains supply?

Yes	No	Maybe	Unsure

If you answered no, why? Please give more information:

Q15

If you answered yes, which of the following sources would you consider using? (if given relevant information).

Please put a tick in the appropriate box.

	Yes	No	Maybe	Unsure
Rainwater (collected from your roof)				
Rainwater (collected from neighbouring roofs)				
Rainwater (collected from surrounding roads/car parks)				
Greywater (collected from your house)				
Greywater (collected from neighbouring houses)				

Q16

Would you consider using rainwater harvesting for any of the following uses?

Please also rate how 'risky' you think the use of rainwater harvesting for that activity would be - please take 'risk' to mean how human health and safety could be affected.

Please insert a value on a scale between 1 and 10, with <u>1 meaning not at all risky</u> and <u>10 meaning extremely risky</u>.

(Please bear in mind that water from such systems is not usually treated beyond filtering, though treatment devices can be added).

	Yes	No	Maybe	Unsure	**Risk rating**
Clothes washing					
Bathing of animals (for example pet dogs)					
Car washing					
Garden watering					
General outdoor use					

In some countries (e.g. Australia) rainwater harvesting is used for things such as drinking and personal washing.
In the UK this is currently not allowed due to water by-laws.

Q17

However, do you think you would consider using rainwater harvesting for:

(Please again insert a 'risk' value between 1 and 10 in the 'Risk' column).

	Yes	No	Maybe	Unsure	**Risk**
Drinking					
Personal washing					
Other uses where water may be ingested (drank/eaten)					

Q18

How would you rate the following performance aspects of the toilet that uses rainwater harvesting?

Please provide additional comments if you have noticed any differences (whether good or bad) compared to a toilet flushed using mains water.

	Good	Adequate	Poor	Please provide additional comments in the lines below
Flush performance				
Cleaning performance				
Noise performance				
Water colour				
Water odour				

Other, please specify:

Q19

How do you feel about any differences you have noticed with the toilet/s (whether good or bad)?

Pleased	Not bothered	Concerned	Unsure	N/A

Have you noticed/experienced any other issues (whether good or bad) with the rainwater harvesting system in general?

Q20

What is your overall opinion of the toilet/s being flushed using a rainwater harvesting system?

Very satisfied	Satisfied	Indifferent	Unsatisfied	Very unsatisfied

Please use the space below for any other comments you would like to make/information you would like to provide. For example if there is other information about your experience with a rainwater harvesting system that does not fit into any of the questions we have asked so far:

Q21

Which of the following benefits do you think having a rainwater harvesting system has?

Please tick ALL that apply.

Saves money on water bills	
Saves valuable highly treated mains water from being flushed down the toilet	
Helps reduce local flooding, as water is stored in an underground tank rather than running down roads	
Helps the environment	
Helps me be more aware of how alternative water supplies work	
Helps me to feel I'm doing 'my bit' for the environment	

Other, please provide more information:

Q22

If your property didn't already have a rainwater harvesting system, how do you think the following factors would affect your consideration of installing one?

	Encourage	Discourage	Indifferent	Unsure
Reducing the amount of tap water used for non-drinking uses				
Wider availability of information about rainwater harvesting systems				
Installation grants/subsidies				
Saving money on water bills				
Water use restrictions (such as hosepipe bans)				
Confidence in those installing it				
Helping the environment				
Helping to reduce urban flooding				
A regular maintenance commitment				
Promotion of such systems by Water Companies				
Promotion of such systems by Government (at any level)				
Promotion of such systems by Environmental Groups				
My neighbour/someone in my street got one				
Meant my water use was not restricted (e.g. during hosepipe bans)				
A relative or close friend got one				
Seeing a working rainwater harvesting system in action				
Having to pay for regular maintenance				
Having disruption to my home/life during the installation (for example, having to dig up the garden to install a storage tank, or making alterations to the roof/guttering, or install extra plumbing)				

Other, please specify:

Q23

If your property didn't already have a rainwater harvesting system, which would make you MOST likely to install one?
Please put a tick next to **ONE ITEM ONLY** (or fill in the 'Other' section)

If I was given a grant	
If I would save money on my water bills	
If we were experiencing a water shortage	
If it helped the environment	
If I had to under new policies/laws	
If my neighbour/someone on my street got one	
If it meant I was not restricted on my water use	
Don't know	
Other, please specify:	

Q24

Do you think it is important to perform routine maintenance of the rainwater harvesting system?

Yes	No	Maybe	Unsure

Q25

How often do you think routine maintenance should be carried out on the rainwater harvesting system?
Please tick ONE only

Monthly	
Four times a year	
Three times a year	
Twice a year	
Once a year	
Once every 2 to 5 years	
Over 5 years	
Never	
Don't know	

Q26

Who is responsible for maintaining the rainwater harvesting system in this property?

A household member	
The landlord	
A rainwater harvesting supplier/maintenance company	
Don't know	
Other, please specify:	

Q27

How often will routine maintenance be carried out on your rainwater harvesting system?

Please tick ONE only

Monthly
Four times a year
Three times a year
Twice a year
Once a year
Once every 2 to 5 years
Over 5 years
Never
Don't know

Q28

Please rank the following maintenance activities in terms of their importance for water quality

Please rank answers - 1 being most important, 4 being least important

Cleaning the catchment surface
Cleaning the filters
Replacing the UV (ultraviolet) lamp (if fitted)
Checking the pump

Q29

Please rank the following maintenance activities in terms of their importance for system function

Please rank answers - 1 being most important, 4 being least important

Cleaning the catchment surface
Cleaning the filters
Replacing the UV (ultraviolet) lamp (if fitted)
Checking the pump

Q30

Not considering who is responsible for maintaining the rainwater harvesting system, how much do you think the above four maintenance activities would cost per year (in £)?

Less than £100 per year
Between £100 and £200 per year
Between £200 and £300 per year
Between £300 and £400 per year
Between £400 and £500 per year
More than £500 per year

Q31

How much would you be prepared to pay for the above four maintenance activities per year (in £)?

Less than £100 per year
Between £100 and £200 per year
Between £200 and £300 per year
Between £300 and £400 per year
Between £400 and £500 per year
More than £500 per year

Q32

How often do you think the following maintenance activities need to be carried out?

Please put a tick next to one answer per table.

To check the pump (this pumps the water from the main storage tank to a header tank in a building)

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To check the pump filter

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To replace the pump (assuming it is not being replaced due to braking down)

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To check the level of sediment in the main tank

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To remove sediment from the main tank

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To drain and clean the header tank/s (if present)

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To check the electrical components of the system

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To check the valves and pipework

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

Q33
Would you recommend installing a rainwater harvesting system to other people?

Yes	No	Maybe	Unsure

Why?

Q34
How easy do you think rainwater harvesting technologies are to use?

Very easy	Easy	Neutral	Difficult	Very difficult

Please explain why (optional)

Q35
Do you think rainwater harvesting is a good thing?

Yes	No	Maybe	Unsure

Please use this space for any other comments you would like to make/information you would like to provide:

Almost finished!
Now just a few questions about you. These will help us compare and analyse the results of the study.

Q36
What age group are you in?

Under 20	
21-30	
31-40	
41-50	
51-65	
65+	

Q37
What is your gender?

Male	
Female	

Q38
Do you have any qualifications? (please tick all that apply)

None	
GCSE	
A-level/GNVQ	
First degree	
Masters degree	
Doctorate	

Other, please specify:

Please note the questionnaire continues over the page……

Q39
What is your occupation?

Q40
Do you own or rent your home?

Owner-occupier	
Shared-owner	
Tenant-private	
Tenant-council	
Tenant-housing association	
Tenant-other	

Q41
How long have you lived in your current home?

Less than 1 month	
Between 1 and 3 months	
Between 3 and 6 months	
Between 6 and 12 months	
Between 1 and 5 years	
Over 5 years	
I am just visiting	

Q42
How many people usually live in your home?

1	
2	
3	
4	
5	
6	
More than 6	

Q43
Does your home have a garden?

Yes
No

If yes and you do not have a water butt (or a suitable location for one), do you wish you could use the rainwater harvesting system for outdoor uses too?

Yes
No

Feedback is an important part of any research project. If you would like to receive details of the results at the end of this study, please tick the box below and include your contact details (this is optional). Furthermore, if you would like to take part in further research, please tick the box below and include your contact details. Please note your details will not be used for anything other than the box you tick.

	I would like feedback
	I would be happy to be involved in future research on alternative water resources

Contact details:

You have now completed the questionnaire. Many thanks for your patience; all of the subjects we have asked you about are very important for our research. Your responses will be recorded in our confidential database and will help us with our research about alternative water resources. Thank you for completing this questionnaire.

University of Exeter

Alternative Water Resources

Gauging your opinions

A study by the Centre for Water Systems
At the University of Exeter

Welcome!

This is a questionnaire about alternative water resources, focusing on rainwater harvesting. Rainwater harvesting is a water-saving technology: rainwater is collected from roofs, stored in a tank and then reused within buildings - see page 3 for a diagram of an example system. This research aims to provide us with data which will allow the provision of better information regarding rainwater harvesting systems. The results are very important to a wide range of organisations.

We hope you can help us by completing this questionnaire. We would ask that the person who pays the water bill (or another adult) completes the questionnaire. Please try to answer all of the questions and as fully as possible. This will help the research to be as detailed as possible and will allow us to make a better interpretation of the results. **Please put a tick next to your choice of answer for each question.**

By completing this questionnaire you are giving consent for your responses to be used, confidentially, as part of this research project. The data you provide in this questionnaire will remain strictly confidential and it will not be possible to identify you or your household from the responses you provide.

Once you have completed the questionnaire, please return it in the stamped, addressed envelope provided.

If you would prefer, you can complete the questionnaire using the internet -

Go to this secure website:	**http://apart.ex.ac.uk/Login**
Enter this Log in code:	**EAC9-E4C1**
Enter this Password:	**password**

If you do complete the questionnaire online, please recycle the paper questionnaire.

If you require any further information about this questionnaire, please do not hesitate to get in touch. Your contact is:

Sarah Ward
Telephone: 01392 263600
Email: sw278@exeter.ac.uk

http://centres.exeter.ac.uk/cws/

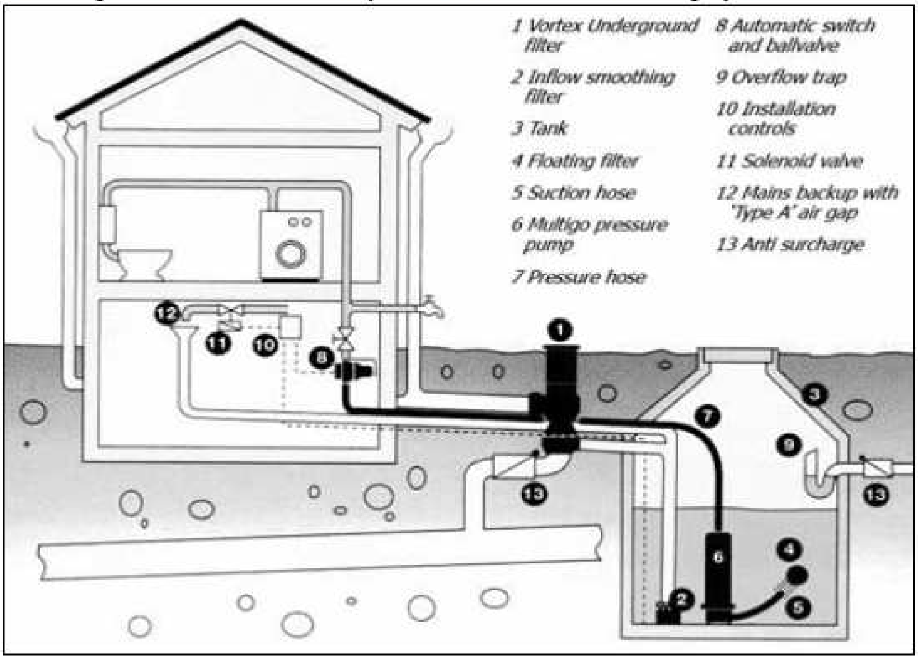
Centre for Water Systems
University of Exeter
Harrison Building
North Park Road
Exeter
Devon
EX4 4QF

A broad definition of rainwater harvesting is:

"rainwater falling on roofs is collected via guttering and downpipes and stored in a tank (usually underground), which is then used within a building - for example for flushing toilets".

Please note, a water butt collects rainwater, but is not a rainwater harvesting system: the rainwater is not piped into a building for use.

This diagram shows the basic layout of a rainwater harvesting system:



Q1
How useful was this diagram in helping you to understand what rainwater harvesting is?

Very useful	Useful	Neutral	Not very useful	Not at all useful

If you would like more information about rainwater harvesting systems, please contact us or visit the UK Rainwater Harvesting Association website (http://www.ukrha.org).

Q2
Have you ever used a rainwater harvesting system?

Yes	No	Maybe	Unsure

Q3
If yes, where was the system?

In a home	In a place of work	Both

Other, please specify:

Q4

If a property already had a rainwater harvesting system, would you be more likely to buy/rent it?

Yes	No	Maybe	Unsure

If yes or no, please give a reason (if possible):

Q5

Have you ever obtained information on or researched into perhaps using rainwater harvesting?

Yes
No

If you answered yes, please give brief details as to what you did/found out:

Q6
Where would be (or would have been) **the BEST place** for you to access information (for example a leaflet) on rainwater harvesting? **Please only TICK ONE.**

In my local library	
In my local DIY store	
In my local council office	
In my local supermarket	
In my local post office	
With my water bill	
At a demonstation site	
None of the above	

Other, please specify:

Q7
How easy do you think rainwater harvesting technologies are to use?

Very easy	Easy	Neutral	Difficult	Very difficult

Q8
Do you think rainwater harvesting is a good thing?

Yes	No	Maybe	Unsure

Q9
Do you consider yourself to be environmentally conscious?

Yes	No	Maybe	Unsure

Q10
Do you value water conservation?

Yes	No	Maybe	Unsure

If possible please give a reason for your answer, for example: 'I value water conservation as it.... helps me save money....prevents wasting natural resources...' or 'I don't value water conservation as....I am too busy....I am not on a meter....' etc.

Q11
Which of the following benefits do you think having a rainwater harvesting system has?
Please tick ALL that apply.

Saves money on water bills	
Saves valuable highly treated mains water from being flushed down the toilet	
Helps reduce local flooding, as water is stored in an underground tank rather than running down roads	
Helps the environment	
Helps me be more aware of how alternative water supplies work	
Helps me to feel I'm doing 'my bit' for the environment	

Other, please provide more information:

Q12

Have you used any of the following water saving devices and if so, how were your experiences with them?

Please put a tick next to one answer per table.

Hippo (or other 'save-a-flush' device) (a device that is put in the toilet cistern; the use of bricks has been known)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Dual flush toilet (a toilet that does a small flush and a large flush)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Slim line toilet (has a smaller cistern, which can also be dual flush)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Other non-standard toilet

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Aerator taps (taps which inject air into the stream of water, making it more bubbly)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Shower head flow restrictor (a device fitted inside the shower head)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Water meter (fitted by a relevant Water Company to the incoming water main)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Water butt (simple plastic storage tanks for the garden)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Rainwater harvesting system (storage tank for uses such as toilet flushing, not to be confused with a water butt)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Greywater system of any kind (greywater is water that has been used once and is then stored, treated and reused for purposes such as toilet flushing)

Used-positive experience	Used-negative experience	Used-mixed experience
Not used	Unsure	

Any others, please specify:	

Q13

Would you be happy to flush a toilet with water from a source other than the mains supply?

Yes	No	Maybe	Unsure

If you answered no, why? Please give more information:

Q14

If yes, which of the following sources would you consider using? (if given relevant information).

Please put a tick in the appropriate box.

	Yes	No	Maybe	Unsure
Rainwater (collected from your roof)				
Rainwater (collected from neighbouring roofs)				
Rainwater (collected from surrounding roads/car parks)				
Greywater (collected from your house)				
Greywater (collected from neighbouring houses)				

Q15

Would you consider using rainwater harvesting for any of the following uses?

Please also rate how 'risky' you think the use of rainwater harvesting for that activity would be - please take 'risk' to mean how human health and safety could be affected.

Please insert a value on a scale between 1 and 10, with <u>1 meaning not at all risky</u> and <u>10 meaning extremely risky</u>.

(Please bear in mind that water from such systems is not usually treated beyond filtering, though treatment devices can be added).

	Yes	No	Maybe	Unsure	**Risk rating**
Flushing a toilet					
Clothes washing					
Bathing of animals (for example pet dogs)					
Car washing					
Garden watering					
General outdoor use					

In some countries (e.g. Australia) rainwater harvesting is used for things such as drinking and personal washing. In the UK this is currently not allowed due to water by-laws.

Q16

However, do you think you would consider using rainwater harvesting for:

(Please again insert a 'risk' value between 1 and 10 in the 'Risk' column).

	Yes	No	Maybe	Unsure	**Risk**
Drinking					
Personal washing					
Other uses where water may be ingested (drank/eaten)					

Q17

How would the following factors affect your consideration of installing a rainwater harvesting system?

	Encourage	Discourage	Indifferent	Unsure
Reducing the amount of tap water used for non-drinking uses				
Wider availability of information about rainwater harvesting systems				
Installation grants/subsidies				
Saving money on water bills				
Water use restrictions (such as hosepipe bans)				
Confidence in those installing it				
Helping the environment				
Helping to reduce urban flooding				
A regular maintenance commitment				
Promotion of such systems by Water Companies				
Promotion of such systems by Government (at any level)				
Promotion of such systems by Environmental Groups				
My neighbour/someone in my street got one				
Meant my water use was not restricted (e.g. during hosepipe bans)				
A relative or close friend got one				
Seeing a working rainwater harvesting system in action				
Having to pay for regular maintenance				
Having disruption to my home/life during the installation (for example, having to dig up the garden to install a storage tank, or making alterations to the roof/guttering, or install extra plumbing)				

Other, please specify:

Q18

Which of the following would make you MOST likely to consider installing a rainwater harvesting system?

Please put a tick next to **ONE ITEM ONLY** (or fill in the 'Other' section)

If I was given a grant	
If I would save money on my water bills	
If we were experiencing a water shortage	
If it helped the environment	
If I had to under new policies/laws	
If my neighbour/someone on my street got one	
If it meant I was not restricted on my water use	
Don't know	
Other, please specify:	

Even if you are not overly familiar with rainwater harvesting, please try to complete the next set of questions as fully as possible - we are not looking for accurate 'answers', we would like to know what ***you think***.

Q19

Do you think it is important to perform routine maintenance of the rainwater harvesting system?

Yes	No	Maybe	Unsure

Q20

How often do you think routine maintenance should be carried out on the rainwater harvesting system?

Please tick ONE only

Monthly	
Four times a year	
Three times a year	
Twice a year	
Once a year	
Once every 2 to 5 years	
Over 5 years	
Never	
Don't know	

Q21

Please rank the following maintenance activities in terms of their importance for water quality

Please rank answers - 1 being most important, 4 being least important

Cleaning the catchment surface		
Cleaning the filters		
Replacing the UV (ultraviolet) lamp (if fitted)		(this kills bacteria within the rainwater)
Checking the pump		

Q22

Please rank the following maintenance activities in terms of their importance for system function

Please rank answers - 1 being most important, 4 being least important

Cleaning the catchment surface		
Cleaning the filters		
Replacing the UV (ultraviolet) lamp (if fitted)		(this kills bacteria within the rainwater)
Checking the pump		

Q23

Not considering who would be responsible for maintaining a rainwater harvesting system, how much do you think the above four maintenance activities would cost per year (in £)?

Less than £100 per year	
Between £100 and £200 per year	
Between £200 and £300 per year	
Between £300 and £400 per year	
Between £400 and £500 per year	
More than £500 per year	

Q24
How much would you be prepared to pay for the above four maintenance activities per year (in £)?

Less than £100 per year	
Between £100 and £200 per year	
Between £200 and £300 per year	
Between £300 and £400 per year	
Between £400 and £500 per year	
More than £500 per year	

Q25
How often do you think the following maintenance activities would need to be carried out?

If you are unsure about any the parts of the system, please refer back to the diagram on page 3.

Please put a tick next to one answer per table.

To clean the rainwater catchment area - usually this is the roof of a house

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To clean the filters (one is fitted where the rainwater is taken out of the main underground storage tank and another is fitted on the pipework inside the building)

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To visually check the level of sediment in the main underground storage tank

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To check the electrical components of the system

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

To check the valves and pipework throughout the system and within the house

Monthly	Four times a year	Three times a year
Twice a year	Once a year	Once every 2 to 5 years
Over 5 years	Never	Don't know

Q26

How easy do you think rainwater harvesting technologies are to use?

Very easy	Easy	Neutral	Difficult	Very difficult

Please explain why (optional)

Q27

Do you think rainwater harvesting is a good thing?

Yes	No	Maybe	Unsure

Please use this space for any other comments you would like to make/information you would like to provide:

Almost finished!

Now just a few questions about you. These will help us compare and analyse the results of the study.

Q28

What age group are you in?

- Under 20
- 21-30
- 31-40
- 41-50
- 51-65
- 65+

Q29

What is your gender?

- Male
- Female

Q30

Do you have any qualifications? (please tick all that apply)

- None
- GCSE
- A-level/GNVQ
- First degree
- Masters degree
- Doctorate

Other, please specify:

Please note the questionnaire continues over the page……

Q31

What is your occupation?

Q32

Do you own or rent your home?

Owner-occupier	
Shared-owner	
Tenant-private	
Tenant-council	
Tenant-housing association	
Tenant-other	

Q33

How long have you lived in your current home?

Less than 1 month	
Between 1 and 3 months	
Between 3 and 6 months	
Between 6 and 12 months	
Between 1 and 5 years	
Over 5 years	
I am just visiting	

Q34

How many people usually live in your home?

1	
2	
3	
4	
5	
6	
More than 6	

Q35

Does your home have a garden?

Yes
No

Feedback is an important part of any research project. If you would like to receive details of the results at the end of this study, please tick the box below and include your contact details (this is optional). Furthermore, if you would like to take part in further research, please tick the box below and include your contact details. Please note your details will not be used for anything other than the box you tick.

	I would like feedback
	I would be happy to be involved in future research on alternative water resources

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Alternative Water Resources

Gauging your opinions

A study by the Centre for Water Systems At the University of Exeter

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Please complete the questionnaire using the following details:

Go to this secure website: http://apart.ex.ac.uk/Login

Enter this Log in code: XXXX
Enter this Password: XXXX

If you require any further information about this questionnaire, please do not hesitate to get in touch. Your contact is:

Sarah Ward
Telephone: 01392 263600
Email: sw278@exeter.ac.uk

http://centres.exeter.ac.uk/cws/

Centre for Water Systems
University of Exeter
Harrison Building
North Park Road
Exeter
Devon
EX4 4QF

Section A

Q1 Have you heard of/considered/used a borehole supply for water?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section B

Q1 Have you heard of/considered/used a borehole supply for water and heat/cooling?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section C

Q1 Have you heard of/considered/used a 'green cluster'?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section D

Q1 Have you heard of/considered/used rainwater harvesting?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section E

Q1 Have you heard of/considered/used water conservation measures?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section F

Q1 Have you heard of/considered/used on-site total wastewater treatment?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section G

Q1 Have you heard of/considered/used on-site greywater treatment?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section H

Q1 Have you heard of/considered/used ‘green water’ and reuse of recycled water?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section I

Q1 Have you heard of/considered/used sustainable urban drainage systems (SUDS)?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section J

Q1 Have you heard of/considered/used a fully integrated water management scheme?

Q2 Was it successful or unsuccessful?

Q3 How and where have you used it?

Section K

Q1 Does your company have a resident water specialist?

Q2 Has or does your company/department/resident specialist consult any guidance documentation on rainwater harvesting before recommending it within a design/project?

Q3 Has your company/department heard of or used any of the following documents?

- BS 8515:2009
- CIRIA Report TN7/2001
- CIRIA Report C539
- CIRIA Report PR80
- EA Document on RWH
- CIRIA Report C626
- The Texas Manual on RWH
- Project Report 1275

You have now completed the questionnaire. Many thanks for your patience; all of the subjects we have asked you about are very important for our research. Your responses will be recorded in our confidential database and will help us with our research about alternative water resources. Thank you for completing this questionnaire.

APPENDIX C FOR CHAPTER 4

(Understanding Stakeholder Receptivity – SMEs)

Contents

- **Interview Introductory Script**
- **Interview Schedules**
- **Interview Transcripts**

Interview Introductory Script

Good Morning/Afternoon/Evening (for telephone)

Could I please speak to X (for telephone)

Dear X (for emails)

I am a PhD researcher at the University of Exeter, investigating rainwater harvesting (RWH).

I have been put in touch with you through the X Scheme, as their records show you were considering/implementing RWH (and possibly other sustainable building technologies).

Part of my research aims to identify how SMEs found the process, right from the feasibility assessment stage to completing installation (if this was done of course!), how they were supported along the way and what they feel could be improved.

If this information is correct and this is something that X has indeed undertaken, it would be fantastic if I could hold an informal interview with you/someone who investigated RWH/dealt with the process.

I look forward to hearing from you; feel free to call if you would like an informal chat (for emails only)

Yours sincerely,
Sarah Ward

==
PhD Candidate
Centre for Water Systems
School of Eng., Computing & Mathematics (SECaM)
University of Exeter
Harrison Building
North Park Road
Exeter
EX4 4QF

TEL: +44 (0)1392 263600
EMAIL: sw278@exeter.ac.uk
WEB: http://eprofile.exeter.ac.uk/sarahward

SME Interview Schedules for RWH Implementers and Non-Implementers

Implementers

1. Where did you first hear about RWH?

2. Why did you decide to install a RWHS?

3. Where did you access information?
    - How did you find this?
    - Had you heard of Envirowise/seen their leaflet?

4. How was/who designed the RWHS?
    - What were the technical specifications?

5. How did you find the process overall?

6. What support did you have along the way?
    - From who?

7. How long did it take to complete the process?

8. How could things have been improved?
    - Simple, complicated or a mixture? What went smoothly, what didn't? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?

9. Has system performance met your expectations?

10. Do you use the fact your business has a RWHS as a promotional tool?

11. Closing section – anything else?

Non-implementers

1. Where did you first hear about RWH?

2. Why did you decide to install a RWHS?

3. Where did you access information?
    - How did you find this?
    - Had you heard of Envirowise/seen their leaflet?

4. Did you investigate system design or technical aspects?
    - Supply-demand balance; maintenance requirements/cost; water quality; were resources adequate to enable you to do this? Did you know where to find information?

5. How did you find the process overall?

6. What support did you have along the way?
    - From who?

7. How long did it take to complete the process?

8. Why was a system not suitable?
    - Simple, complicated or a mixture? What went smoothly, what didn't? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?

9. What could have been done to improve chances of implementation?
    - If nothing, why? If something could have been done, why wasn't it?

10. Closing section – anything else?

Transcript 1: Farm

Implementer

1. Where did you first hear about RWH?

A sustainability audit was carried out on the entire X's operations by Envision – RWH was recommended for X (another premise in Torquay). Midas were the main contractor and advised, along with the architect, Stratton and Holbrow, that RWH could be included. Initially the sustainability assessment was revised back, due to funding levels, but it was decided to install the main tank.

2. Why did you decide to install a RWHS?

Sustainability drivers – wanted to be as eco as possible across all operations.

3. Where did you access information?
    - How did you find this?
    - Had you heard of Envirowise/seen their leaflet?

Hadn't really heard of them then. Had more involvement with Envision right from 2003. Not seen the leaflet.

4. How was/who designed the RWHS?
    - What were the technical specifications?

Sort of through the sustainability assessment (SA), although we didn't assess properly any financial savings as sustainability was main driver.

Probably. Envision, via the SA, recommended we get one (a water audit) from SWW. All parties – X in charge of ordering parts; he figured out the installation details/parts required with JTT then placed orders. JTT and RWH Ltd were perhaps involved in deciding the initial tank size; no specific size request made as far as X knows – unsure as to what they based their estimate of tank size on, as the demand was not known at the time of design. See .pdfs for technical specs. X was also not sure if the system was properly tested or commissioned by Beale and Cole – 'I'm sure they would have done commissioning'. SWW were asked to sponsor water efficient goods – they eventually provided some meters and a computer to display water use read outs (these have yet to be connected up/made operational).

Midas and Stratton and Holbrow were pretty helpful through the process.

Felt like we were having to play catch up – it wasn't a priority until the last minute – it wasn't worked into the work plan. RWHS was a casualty of non-tight project management – we relied on the developer and architect to do this for us via fortnightly meetings. Learnt that we needed a dedicated project manager to deal with things, to pick up threads and run with them – would do that now. X was unofficial project manager and ordered parts/liaised with suppliers/contractors etc, but had other projects to deal with also. Hence why it took so long to implement. Lots of emailing over many months (2 years) to confirm orders/specs/costs etc.

Beale and Cole were also learning as they went along – which I realised when the parts arrived and they picked up the instructions.

5. How did you find the process overall?

A bit time consuming – I was project manager in absence of anyone else and had other things – didn't have time to focus on it. Conversations drove the project.
Felt complicated, definitely, yeah. Once you could see the instruction sheet it looked complicated, probably straight forward to a plumber.

X ordered parts and gave them to the Beale and Cole plumber, who was left to figure things out and install (remember them looking at instructions and trying to figure it out!) – no project manager so things were done last minute.

6. What support did you have along the way?
    - From who?

No specific support was identified. All the parties helped each other muddle through.

Would have undoubtedly been good to have a support organisation to go to – we were making it up as we went along.

7. How long did it take to complete the process?

3 years (2003 – 2006). As it was added back in after taken out due to shortfall in S106 funding (eventually the rest of the system parts were accounted for in overspend).

8. How could things have been improved?
    - Simple, complicated or a mixture? What went smoothly, what didn't? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?

Best thing should have been the architect who was fully aware of the ins and outs and should have built it into the M&E contract.

The cost of the pump was outside of the contract and the installation cost was omitted so overspend was outside S106.

Having enough funding upfront may have made things run more smoothly.

9. Has system performance met your expectations?

Yes, I do think it has actually. Sediment issues are interesting. Also interesting to see what meters say – shall we have a look (proceeded to enter the roof space to take meter readings, given earlier in this document, as well as photos – see final page).

10. Do you use the fact your business has a RWHS as a promotional tool?

Not especially – although our big thing is sustainability, so it's part of that really.

11. Closing section – anything else?

Maintenance:

No maintenance schedule is in place and no advice/guidance was given from any party (i.e. supplier/installer) to the X on recommended frequency or the type of activities to undertake – they were left to figure it out. Maintenance is provided by Beale and Cole and is provided on an ad hoc basis (i.e. called out when needed). There is no proactive maintenance regime. Care taker occasionally checks the coarse debris filter (which he did a few days ago).

We're not very systems orientated – across the whole organisation really - all maintenance is done ad hoc, all utilities, as things are thought to be needed – when we remember something might need a service.

Sediment is a real issue in the main tank – accumulated before the full system was installed (i.e. between 2004-06) and the sludge has been cleaned out once with water and suction. So there's a historic sediment legacy there. Bit random but mainly seen after any rainfall event.

Problems:

Solenoid was faulty 18 months ago. Mains was continuously on and therefore would cascade out of the overflow. If you wiggled the connection to it, it stopped therefore we knew it was a bad connection. Took Beale and Cole months to admit a faulty connection on the solenoid was responsible – they sent out several different engineers. They changed it eventually after tooing and froing.

Other sustainability features:
PV on barn roofs.

Other:
During the visit we looked at the main tank in situ – removed manhole cover and lifted pump out of tank. It was covered in sediments, as was the filter draw-off. We tested it by raising the sensor and it worked. We cleaned and replace it. Tank level was below level of sensor – hence system was currently using mains water.

Transcript 2: Animal Charity

Implementer

1. Where did you first hear about RWH?

The previous environmental officer (EO) for Croc Swamp (built 1 year ago) wanted to do lots of sustainability features (solar, woodchip etc) and decided it would be good to have RWH – he has now left leaving the legacy of systems that are not fully up to scratch.

2. Why did you decide to install a RWHS?

The water bill at X is currently ~£50k/yr, this was the biggest incentive, but also huge sustainability drivers across the whole charitable trust.

3. Where did you access information?
    - How did you find this?

Don't know where the previous EO got his information from.
No and no, don't think the EO would have either.

4. How was/who designed the RWHS?
    - What were the technical specifications?

No, we didn't consider the demand/uses that the water would be used for. From what we know the supplier was given the roof size and asked to accommodate that.
Probably, if we had known what the water was eventually going to be used for and had an idea of the demand we wanted to satisfy.
No, as already mentioned, the roof size was the only thing used to design the system.
X has its own maintenance crew, so we didn't think maintenance would be an issue. No one mentioned regular maintenance during the installation and we don't have a schedule or any documents for it – we do it as and when we think it needs doing.

No site visit was carried out to assess the area surrounding the proposed site of croc swamp. I guess if it had the seagull/poo issue would have been identified as the site is right next to the composting bays where the seagulls like to hang out as it's a source of food for them.

Hoarelea of Plymouth (http://www.hoarelea.com/contact/office.cfm?content_id=9) were the M&E and Advance Builders did the groundworks (installation). Rainharvesting Systems (http://www.rainharvesting.co.uk/) supplied the system, presumably they just went on the roof size they were given. Adrian on the maintenance team deals primarily with croc swamp and the water systems (including the borehole pipework).

5. How did you find the process overall?

X (maintenance): the supply and installation was no problem – the groundworks went very well and the system was fitted quite easily.

Operationally, we've had nothing but problems. There was a problem with sediment collection, but we did a £600 confined clean of the main tank and thought we'd resolved it, but there's still a lot of sediments coming in. Once the filter on the floating draw-off collapsed due to the pressure on it as the pump was over-compensating because of the sediments coating it. As you've seen the roof is covered with gulls and their debris, which means X advised the water shouldn't be used in with the crocs (note: X had carried out micro analysis using SWW laboratory to establish WQ).

X: The internal filters and UV don't work as the flow through it is too high (due to the bore of the pipe). So water is basically forced through them with all the sediment going through as well and of course the resultant decrease in residence time means the UV is virtually doing nothing.

6. What support did you have along the way?
    - From who?

I think the EO left it to the M&E and groundworks people and the architects to sort out all the technical side of things – I am assuming he assumed they were the experts.

From contractors really – we didn't know that the site should have been thought about more carefully (hindsight is a great thing) or about the post-installation things like maintenance.

7. How long did it take to complete the process?

18 months from when the building was first designed to actual construction.

8. How could things have been improved?
    - Simple, complicated or a mixture? What went smoothly, what didn't? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?

If we'd have known or thought about the gull issue, maybe we would have installed it on a different building – there are others which have cleaner roofs.

X (in conjunction with SW) has now recommended a first flush device/tank, as all other more pro-active options (catchment cleaning) are limited by the nature of the roof construction.

9. Has system performance met your expectations?

Definitely not! We've got to do lots of remedial work to get it functional.
No, as it hasn't really worked since it was installed. The management are also reluctant to fit RWH anywhere else on the site (or other sites) as it's seen as a failure.

10. Do you use the fact your business has a RWHS as a promotional tool?

11. Closing section – anything else?

Transcript 3: Hotel

Implementer

1. Where did you first hear about RWH?

Direct experience – used to live in Germany.
Via www 5-6 years ago

2. Why did you decide to install a RWHS?

Primarily to save money through water efficiency, plus was very interested in it.

3. Where did you access information?
    - How did you find this?
    - Had you heard of Envirowise/seen their leaflet?

WWW – did a lot of searching
Have now, hadn't back then; No – could have been promoted better – needs to be with a WSP bill or something.

4. How was/who designed the RWHS?
    - What were the technical specifications?

I did – I'm a plumber by trade.
It's a gravity system, designed for low noise, low cost.
Had one supplier in for a quote, but he did the hard sell and when questioned on data, he had no real data to back up his claims.
Metering and measurements over 7 years, obtained personally

SWW did one (an audit), after we asked them – we went to them for information as they seemed the natural place to seek information on water. They gave information on water efficient goods and advice on suppliers.

5. How did you find the process overall?

Complicated initially and then got easier.
Made complicated by the planning department, who saw it on the TV (or head about it via a ‘nosey nasty’ neighbour) and as we hadn’t sought planning permission for it, they chased us and got involved.
We’ve applied for PP and are currently waiting to hear if PP has been granted retrospectively (hopefully within a month).
WWW gave enough information – I knew about all the WRAS etc, as went on an extra course to bring myself up to speed. I can’t see many other plumbers doing this, so there’s a deficit in expertise, which doesn’t help other businesses when they’re trying to consider these things. Lack of awareness in existing plumbing base and a lack of willingness/motivation to do anything extra e.g. read WRAS etc.

6. What support did you have along the way?
    - From who?

SWW – were great regards water efficiency suppliers

Other SMEs might be put off due to not having personal resources to investigate all efficiency aspects and someone they cab trust to carry out the work.

7. How long did it take to complete the process?

Roughly 2 weeks for the RWH.
Designed to have minimal disruption during installation – proactively designed out all possible conceived problems (planning, calculations, measurements etc); this was essential to minimise stumbling blocks.
Did exterior work out of peak B&B hours.

8. How could things have been improved?
    - Simple, complicated or a mixture? What went smoothly, what didn’t? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?

A more helpful and proactive planning department (Exeter City Council) – it has been very costly and time consuming (‘a jobs worth’, who’s not very flexible/amenable). Cost accrued due to planners has outstripped financial benefit of having the system. Perhaps a ‘buddy’ system – mentors on a database, similar sized SMEs who already have done it and can guide others – e.g. demonstration sites that are actually functioning/monitored businesses, so you can see how it operated and how they benefit. Planning – they don’t look at the whole picture i.e. how I’m helping save resources of the area and what that contributes (Environmental Health were great when they came to assess the system for H&S congratulated me on doing a great job, but planning officer is a nightmare – total opposite (a small-minded bureaucrat!)).
Plumbing wasn’t a problem, but I know other people have been put off doing it by lack of expertise/information on plumbers. Also that people aren’t willing to pay to do these things.

9. Has system performance met your expectations?

Definitely.

10. Do you use the fact your business has a RWHS as a promotional tool?

Not yet, will do in the future though – but passively; information will be available via the web if a customer wants to navigate through it and find out more.
(X has won several green awards, therefore the intonation in its credentials is there).

11. Closing section – anything else?

We did know about ECA, but as the capital and installation costs were minimal, it was not beneficial to try to claim the tax back in this way. The increase in the accountants charges would wipe out any gain. The aerated shower heads were from the WTL, but again, not worth claiming back specially.

Transcript 4: Office

Implementer

1. Where did you first hear about RWH?

NA

2. Why did you decide to install a RWHS?

X decided to include sustainability features within the building in order to fulfil a range of sustainability agendas.

3. Where did you access information?
   - How did you find this?
   - Had you heard of Envirowise/seen their leaflet?

Architect (Penrose), consultancy/designer (Halcrow) and developer (Kier) contacted Stormsaver for a quote. Also looked at BREEAM.

4. How was/who designed the RWHS?
   - What were the technical specifications?

Halcrow/Kier/Mitie the building/internal workings and Stormsaver the actual RWHS equipment.

5. How did you find the process overall?

Complicated – lots of coordination between stakeholders required which inevitably produced delays, complications and conflicts of responsibility.

Installation and commissioning did not go smoothly. Despite recommendations made within Stormsaver's commissioning report that float sensors were not configured correctly, this was not rectified until reiteration to responsible parties many times through the building management team. It appeared they were constantly battling against the 'it's not our responsibility' mentality adopted by the implementation team.

Lack of RWHS implementation project management experience and an overall lack of experience with RWHS (and not having Stormsaver present for more than one day when the main underground storage tank was installed). The Building Management System (BMS) was also incorrectly configured for the RWHS.

6. What support did you have along the way?
    - From who?

PhD student from SECaM was monitoring the system and therefore could keep an eye on whether it was working or not. Buildings and Estates provided some support in terms of maintenance activities, although were reluctant to do more than absolutely necessary arguing that remediation measures (bird-proof netting etc) should be implemented under the contractual obligations of the building designers/constructors.

7. How long did it take to complete the process?

Over two years from system consideration/building design, through construction and to achieve full system operation.

8. How could things have been improved?
    - Simple, complicated or a mixture? What went smoothly, what didn't? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?

Probably, although sometimes the information was not with or relayed to the appropriate organisation/individual.

Yes and no. Multiple decisions in implementation of RWH is only to be expected. However, the main sources of confusion and inadequate implementation arose due to a lack of communication between implementing parties and a reluctance to take ownership of problems that arose.

Less actors – one party with overall responsibility for the entire system should have been agreed from the beginning – this could have easily been Kier as they were the overall project managers. More advice on guidance about the implementation process itself, rather than technical manuals and system specification. Improved training for implementers too.

Also more attention could have been paid to the system control panel and better response times provided by Stormsaver – at one point the system was not functioning due to an automatic backwash valve becoming seized, causing it to pump against a closed head. Stormsaver scheduled to visit when they were next in the area, which was several weeks later. The valve was replaced but the time delay could have put pressure on the pump and also caused it to fail, generating unnecessary cost implications.

The inclusion of a RWHS could have been more greatly considered in the initial building design. Many aspects of the building design were identified as having implications for RWH water quality.

9. Has system performance met your expectations?

Well, we expected teething problems and those were exactly what we got. System miss-configurations, lack of maintenance (clogging of filters) etc.

But generally yes, the system has provided a good level of supplementation of the mains supply for WC flushing.

10. Do you use the fact your business has a RWHS as a promotional tool?

Not directly, but indirectly in terms of the overall sustainability features of the building.

11. Closing section – anything else?

There is a maintenance contract with the supplier, which was negotiated over some time, as B&E felt they could do some, so this had to be negotiated to bring the contact cost down but still provide warrantee cover. B&E do not have a schedule for their bits.

Transcript 5: Cafe

Non-implementer

1. Where did you first hear about RWH?

RE4D (Renewable Energy for Devon) – part of the Devon Renaissance (DR) Scheme for redundant buildings; an environmentally friendly package for small businesses. Included an feasibility assessment for renewable energy, plus RWH

2. Why did you decide to install a RWHS?

We are on a 30-year lease; anything we can do to reduce overheads/resources would give us a competitive edge over the competition, especially if the capital outlay is covered by a grant.

3. Where did you access information?
    - How did you find this?
    - Had you heard of Envirowise/seen their leaflet?

Report was sent by the DR consultant after a site visit – mentoring sessions were limited. Never heard of them (not even 4 yrs ago when system was first considered); No to leaflet**.** DR – consultants. WWW – background research

4. Did you investigate system design or technical aspects?
    - Supply-demand balance; maintenance requirements/cost; water quality; were resources adequate to enable you to do this? Did you know where to find information?

DR consultant came and assessed – WCs were calculated, but trouble calculating the demand of a commercial kitchen (i.e. including dishwasher usage – this was considered to be connected to the RWHS). No independent companies offering these services back then (it's changing now).

Yes, may have had one (an audit) with SWW via the consultant, but I don't know 100% if we did or not (as wasn't told such). RWH was pretty much shelved before this could be done properly. SWW were very unhelpful regards mains installations though.

DR consultant explored above/below ground options.
Didn't get to costing stage. Not really – as was deemed unfeasible after initial investigations.
Yes, required by Network Rail as they would take ownership if our lease ceased etc.
Not in detail, but considered roof type/design in relation to WQ.

We left it to the consultant, no suppliers were bought in as far as I know (it didn't get to that stage).

Below ground – land not suitable – marshland, deemed unstable/didn't want to excavate;
Above ground – Heritage Trust (oversaw approval of all plans) had issues with above ground (vessel aesthetics) – also area available was not enough. Furthermore Network Rail would have required any above ground storage to be fully lockable/in a lockable compound, thus increasing costs.
Feasibility assessment stage – it wouldn't fit.

Left feeling that it would have been costly to maintain and there were better ways to protect the environment/reduce overheads (e.g. turned to major water efficient devices retrofit – waterless urinals, dishwashers).

Security (lockability of storage vessel)

Would have made the renovations a lot more lengthy and problematic than they already were! (would like to see figures comparing CO2 of small scale RWH & mains)

5. How did you find the process overall?

6. What support did you have along the way?
    - From who?

Heritage Trust
Not from industry – no local companies who we could mull things over with i.e. no competent supplier locally and didn't want to draft in expertise from further a field as time requirements on site would have increased costs.

7. How long did it take to complete the process?

A few hours for assessment, then paperwork.

8. Why was a system not suitable?
    - Simple, complicated or a mixture? What went smoothly, what didn't? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?

DR were reluctant to 'get involved' other than to assess for grant eligibility – no 'phone a friend'.
They didn't want to get involved in practical or contractual issues – lack of responsibility. This is required, especially with a scheme aimed at getting SMEs involved, who have low buffers should anything go wrong – nothing to cover extra costs incurred via poor workmanship (couldn't be reclaimed via RE4D).
No post-project support or guidance, or help with problem-fixing/bad workmanship issues (very much seen as 'your problem').
Increased confidence in the process/system.
A test case site – implemented so you can see what happens, rather than feeling like the guinea pig.
Improved contractors list for areas – such as you can get for renewables.
Different system designs for heritage buildings.
The system is not well organised enough to support everything and you're left to sort it out.

Practicalities of building: technology available not suitable for building and lack of support.

The railway is very behind in terms of sustainability.

The whole process felt like ‘tick in the box’ stuff on the part of the scheme.
Post-installation process/support is non-existent – there needs to be more support as a lot of people have been burnt – often grant is not sufficient to cover project. 20-40% contribution is not enough for small SMEs.
Not enough confidence or expertise – some companies don’t give a monkeys!

DR Redundant Buildings Grant – applied to rural areas, but X got in on the basis that if the station closed there would be numerous job losses to the local rural area.

9. What could have been done to improve chances of implementation?
    - If nothing, why? If something could have been done, why wasn’t it?

10. Closing section – anything else?

Other plans included:

Ground Source Heat Pump – not enough/wrong type of land;
Air Source Heat Pump (to be implemented);
Solar panels – problems with Network Rail and Heritage Trust (lost grant, but hoping to install this in an extension, should this get the go ahead);

For any commercially land lorded premises – submit works proposals to landlord on lengthy form to get approval;
He then has 45 days to consider them (can be pushed up to 80 days);
An interim lease comes into play and full lease is not granted until all works are completed, inspected and agreed with landlord.
In this case the form was submitted 3 years ago and is still ongoing, as works are yet to be completed.
(In relation to Network Rail – their LC policy has changed significantly in 4 years).

Transcript 6: Craftsman

Non-implementer

1. Where did you first hear about RWH?

After thinking about water usage did a bit of www searching. Then through Devon Renaissance (DR) after applying for a grant – it was one of their recommendations and pointed out in the options from the environmental chap.

2. Why did you decide to install a RWHS?

Saving on water bills and we have a lot of roof space, wanted to try to make use of it, but everything was subject to cost-benefit. After you consider the roof area and start looking into system details it gets more complicated!
We also use a lot of water for washing down carriages/horses/watering them etc, so doesn't need to be drinking quality. I hate waste too and when we have a thunderstorm and all the water gushes out into the ditch at the end of the tunnel, I just think God what a waste, we could be using that. Psychologically we should do it.
Not a sustainability/carbon thing as I think that has all been blown out of proportion – it's just the Government building it up to make us pay more taxes on things.
Saving is primary driver though, it's got to be a balance.

3. Where did you access information?
    - How did you find this?
    - Had you heard of Envirowise/seen their leaflet?

Internet

No and no, but it looks like it might have been useful as an introduction.

4. Did you investigate system design or technical aspects?

- Supply-demand balance; maintenance requirements/cost; water quality; were resources adequate to enable you to do this? Did you know where to find information?

No. The tank people want to sell you a tank and the pump people want to sell you a pump. Too many parties to deal with – tank pump, installation etc. I think whoever promotes this sort of thing needs to have an independent person to come and tell me 'this is what you need to do, it will cost X', then it would make things easier. The n you could make a decision. I hate finding things out and don't have time to look at all the options etc. A site/feasibility assessment and costs etc would be great, then I would know they can take care of the whole process [like having a project manager] – I don't want to know all the detail, I just want to pay when it's finished and use it.

No, another thing I'd not really considered. Hadn't thought about sediments, technical issues, site things like etc. Though I guess it's the 'invisibles' that add up, which may or may not make it cost effective.

5. How did you find the process overall?

Very complicated!

We were building a new site of several large buildings, which became very stressful due to planning and building inspection issues – they weren't very flexible. We rebuilt rather than renovated one of the buildings as it was about to fall down and then they made us re-apply for planning permission even though we rebuilt it exactly the same as it was before. Also the building regulations changed between applications, so we had to submit extra drawings at extra costs. Additionally, as we'd done everything through DR we had to meet their strict criteria on building regulations etc because of it being public money and all that. So we were doing things beyond the specification we needed to comply with for our requirements. Basically we overspent beyond the level of the grant because of that and so it was all so stressful I decided doing RWH at the same time was too much hassle. The dates on the grant were also restrictive and so there was too much to consider in too little time.

Planning and building inspectors.
Planning were horrendous – put me off doing it quite frankly.

Yes – we needed to know so much about all this technical stuff, which was all too much, both time and stress-wise!
We took on an awful lot – it wasn't as important at the time as getting the workshops up and running.
Not really. No independent RWH expert person not trying to sell a thing.

6. What support did you have along the way?
    - From who?

DR mainly – they were excellent and very supportive, as far as they could be.
No and wasn't given any detailed information by anyone.
No, didn't search that far and wasn't given any information on that (even by DR) – hadn't really thought about those things and didn't really have the time or inclination

7. How long did it take to complete the process?

Construction: 2 years, due to hiccups – more involved that we thought.

8. Why was a system not suitable?
    - Simple, complicated or a mixture? What went smoothly, what didn't? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?

9. What could have been done to improve chances of implementation?
    - If nothing, why? If something could have been done, why wasn't it?

A working site - might make sense to see one – wouldn't want to travel far, be nice if they were hospitable. Though I would want it to have been there for about 5 years to see the pitfalls and benefits [not perceived as a tried and tested technology].
Yes, something could've been done – want someone to show me what's needed and what to do and come along and do it.
Also, better information and perhaps one place to contact to tell me all the things required.

Not the right time and we didn't have time to find out where the right people were.

Also looked at a borehole – company came and did an assessment and surveys etc and found it was not feasible due to greensand – would have needed an expensive concrete lined shaft. Spent £500 to find that out if wasn't feasible. That's already added to my water bills cost. So any RWH assessment would need to come from the Government funds, or at least part funded, 50% maybe. If you're only saving a little, you're not going to want to put a lot of money up front. The last thing you want to do is spend a lot of money and 5 years down the line say we wished we hadn't done it. Are there any grants for these things available like for the microgeneration [informed about ECA and current Government stance on grants/subsidies]

DR – grant process hasn't put me off that though, we just took on too much.

General – problems with planning and construction made everything stressful, so decided to put it on the back burner and reconsider it later.

10. Closing section – anything else?

Transcript 7: Charity

Non-implementers

1. Where did you first hear about RWH?

ENVISION – small assessment and guidance.

2. Why did you decide to install a RWHS?

Financial reasons – current water bill is £17,000 – this could be vastly reduced as majority of uses do not require potable level quality (e.g. washing cows feet). But also as we are a charity, it is good to be seen to be being more environmental, but it also something that we aspire to do to have a lower environmental impact.

3. Where did you access information?
    - How did you find this?
    - Had you heard of Envirowise/seen their leaflet?

No, did a lot of research using google etc, though Envision were good and I did sign up to their email news update service.

4. Did you investigate system design or technical aspects?
    - Supply-demand balance; maintenance requirements/cost; water quality; were resources adequate to enable you to do this? Did you know where to find information?

Yes, carried out a self-audit, using in-house knowledge of consumption and roof areas. Called the Met Office for rainfall data.

Hadn't really thought about asking SWW, as we pay their bill – didn't really think they would be happy to help us reduce our consumption, as it's not really in their interests i.e. we'd be paying them less – seemed illogical!

Yes (see attached document) – using local/in-house knowledge & Met Office data.
No, not yet - hadn't really thought about this (maintenance) aspect, but being on a farm there would be lots of in-house expertise, which would keep costs to a minimum, but it is something else to think about.
No, hadn't really thought about this – being on a farm you just take it for granted really that rainwater is going to be clean.
Luckily have good in-house knowledge (as one employee is responsible for sorting out drainage etc, so there is a good connection with water in terms of how it is viewed/knowledge about it).

5. How did you find the process overall?

It was an unknown process – sort of developed as we went along, getting deeper into the information as it went, but not immediately knowing what to do next/next steps. Quite frustrating.

6. What support did you have along the way?
    - From who?

Envision – who we'll probably contact again now I revisited the water project.
Also contact the Lottery fund, to pursue funding for RWH/energy more with them through the environment stream.

7. How long did it take to complete the process?

Still ongoing – through water project was started a year ago (April 2008) – it's a project we keep having to chip away at. It's a bit circular, because of the uncertainty regards the funding.

8. Why was a system not suitable?
    - Simple, complicated or a mixture? What went smoothly, what didn't? What obstacles arose? Were there too many decision points? Was there enough information to support your decision making?

Once we knew what we needed to do, yes.

No funding to purchase equipment or install it – currently hastily trying to seek funding – water project was initiated about a year ago, during which the first bungalow has almost been completed and the foundations laid for the other two. We have funding to complete the bungalow, but not to install the RWH etc; trying to find grants to apply for which cover that sort of thing.

We'll be going ahead with the plans at some point – it's just taking longer than we thought, because of the lack of securing funding/need to identify/apply for grants etc.

9. What could have been done to improve chances of implementation?
    - If nothing, why? If something could have been done, why wasn't it?

Would be useful to have a source to go to – Envision have been good, but something for water would be useful – whether an independent group, or knowing that we could have approached SWW and the help they can provide (didn't naturally think this would be available from them).

No, nothing I can think off – apart from making funding mechanisms for this sort of thing easier! We know what we need to do and the benefits that will come with that, we just currently don't have the funds to do it. Regular funders don't want to just pay for running costs – but they're happy to pay for projects that will help us reduce the running costs – hence you have to think outside the box regards applying for funding and make proposals stick out from the crowd i.e. be different to the other charities also applying for the funding.

10. Closing section – anything else?

APPENDIX D FOR CHAPTER 5

(Understanding RWH System Performance – Water Quality Assessment)

Contents

SOUTH WEST WATER

Certificate of Analysis

Sample Number: 1568267

FAO: Robert Wynn
South West Water Ltd
Metering & Conservation Services
Peninsula House
Roydon Lane
EXETER

From: SWW Scientific Services
Exeter Laboratories
Bridge Road
Exeter
EX2 7AA
Tel: 01392 434136
Fax: 01392 421419

Sampled date:	4-Aug-2008 09:50
Collected from:	(1) CENTRAL PLANT ROOM
Material code:	Precipitation (E02)
Purpose code:	Private (P)
Sampling method:	Single spot (S)
Sampler observations:	PROCEEDING WEATHER: + HEAVY RAIN ON DAY PRIOR TO COLLECTION + GENERALLY SUNNY AND SHOWERY TANK FILTER CLEANED LATE JUNE
Date Sample Received:	4-Aug-2008 11:51
Date authorised:	15-Aug-2008 21:31
Sampler:	S WARD (SWARD)

MICROBIOLOGY

Bacteriology	Result	Unit	Notes	Limits
Presumptive Total coliforms by membrane filtration	960	no/100ml		
Presumptive Faecal coliform by membrane filtration	770	no/100ml		
Presumptive Faecal strep by membrane filtration	830	no/100ml		
TVC by pour plate at 22 `C for 3 days	6600	no/ml		
TVC by pour plate at 37 C for 2 days	3000	no/ml		
Confirmed Salmonella sp by most probable no.	0	no/100ml		

Protozoa	Result	Unit	Notes	Limits
Confirmed Crypto.oocysts by chem.floc/IMS				
Am.t of samp. analysed	10.000	l		
Vol sampled	10.0	l		
No.of oocysts in vol examined	0	no		
No of oocysts/l	0.000	no/l		

INORGANIC CHEMISTRY

General Chemical Analysis	Result	Unit	Notes	Limits
Hydrogen ion conc (by pH Electrode)	7.6	pH units		
Conductivity at 20`C (by Electro Conductivity)	88.4	µS/cm		
Total Dissolved Solids (by calculation)	61.9	mg/l	#	
Turbidity (by Nephelometry)	0.8	NTU		
BOD 5 Day ATU as O2 (by ISE)	<3	mg/l	<	
COD mgO2/l (by Redox Spectrophotometry)	<10	mg/l	<	

Nutrients & other Anions	Result	Unit	Notes	Limits
Nitrogen Total Oxidised as NO3 (by Colorimetry)	6.33	mg/l		
Ammonium as NH4 (by Colorimetry)	0.01	mg/l		
Nitrate as NO3 (by calculation)	6.33	mg/l		
Nitrite as NO2 (by Colorimetry)	<0.01	mg/l	<	
Chloride as Cl (by Colorimetry)	5	mg/l		
Phosphorus as P (by ICPMS)	<50	µg/l	<	
Silicate React. Dissolved as SiO2 (by Colorimetry)	0.97	mg/l		

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UKAS TESTING 1361

SOUTH WEST WATER

Certificate of Analysis

Sample Number: 1568267

Nutrients & other Anions	Result	Unit	Notes	Limits
Sulphate Dissolved as SO4 (by ICPMS)	5.3	mg/l		

Metals	Result	Unit	Notes	Limits
Calcium as Ca (by ICPMS)	10	mg/l		
Magnesium as Mg (by ICPMS)	0.37	mg/l		
Potassium as K (by ICPMS)	2.4	mg/l		
Sodium as Na (by ICPMS)	4.3	mg/l		
Aluminium as Al (by ICPMS)	80.2	µg/l		
Iron as Fe (by ICPMS)	<9	µg/l	<	
Manganese as Mn (by ICPMS)	<2	µg/l	<	
Copper as Cu (by ICPMS)	218	µg/l		
Zinc as Zn (by ICPMS)	193	µg/l		
Lead as Pb (by ICPMS)	25.5	µg/l		
Cadmium as Cd (by ICPMS)	<0.4	µg/l	<	
Chromium as Cr (by ICPMS)	<0.5	µg/l	<	
Nickel as Ni (by ICPMS)	<1.5	µg/l	<	

ORGANIC CHEMISTRY

Miscellaneous analysis	Result	Unit	Notes	Limits
Oil & Grease (Total) by IR	<1	mg/l	# <	

Polycyclic Aromatic Hydrocarbons	Result	Unit	Notes	Limits
Benzo[a]Pyrene (Total) by HPLC/Fluor	<1	ng/l	<	
Benzo[b]Fluoranthene (Total) by HPLC/Fluor	<0.001	µg/l	<	
Benzo[ghi]Perylene (Total) by HPLC/Fluor	<0.002	µg/l	<	
Benzo[k]Fluoranthene (Total) by HPLC/Fluor	<0.001	µg/l	<	
Indeno[1 2 3-cd]Pyrene (Total) by HPLC/Fluor	<0.003	µg/l	<	
Polycyclic Aromatic Hydrocarbons (Total)	0.000	µg/l		

Under the authority of

Claire Coppin
Laboratory Services Manager

Date Issued : 18-Aug-2008

Key to abbreviations and notes:

< Result less than reported value ie: is below the Limit of Detection for that method
Analysis not included in UKAS accreditation

Details of date(s) analysis commenced, analytical methods and estimated uncertainty of results are available from the Laboratory address above. The results are given for the sample as received by the laboratory. Sampling is outside the scope of UKAS accreditation. Opinions and interpretations are outside the scope of UKAS accreditation. This Certificate of Analysis shall not be reproduced except in full, without the written approval of the laboratory. For Microbiology tests, zero means 'not detected per volume examined'.

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UKAS TESTING 1361

Category			-0.420662716				Microbiology	-0.375363802			-0.176232553	
Sub-cat							Bacteriology					
Determinand			Total Coliforms (TC)	TC BSI/MTP suggested for WC (cat C	TC EC Bathing (G)	TC EC Bathing (I)	Faecal Coliforms (FC)	FC Bathing (G)	FC Bathing (I)	FC WRAS (CIRIA C539)	Faecal Strep (FS)	MTP/BSI
Unit	Done	Results	no/100ml	1000	500	10000	no/100ml	100	2000	10000	no/100ml	100
04/08/2008	✔	✔	960	1000	500	10000	770	100	2000	10000	830	100
11/08/2008	✔	✔	52	1000	500	10000	52	100	2000	10000	28	100
18/08/2008	✔	✔		1000	500	10000		100	2000	10000		100
26/08/2008	✔	✔	2600	1000	500	10000	1500	100	2000	10000	32	100
01/09/2008	Miss	Miss		1000	500	10000		100	2000	10000		100
08/09/2008	✔	✔	400	1000	500	10000	170	100	2000	10000	560	100
15/09/2008	✔	✔	650	1000	500	10000	560	100	2000	10000	760	100
22/09/2008	✔	✔	240	1000	500	10000	150	100	2000	10000	90	100
29/09/2008	LOW LEVEL, NO			1000	500	10000		100	2000	10000		100
06/10/2008	LOW LEVEL, NO			1000	500	10000		100	2000	10000		100
13/10/2008	LOW LEVEL, NO			1000	500	10000		100	2000	10000		100
20/10/2008	LOW LEVEL, NO			1000	500	10000		100	2000	10000		100
27/10/2008	LOW LEVEL, NO			1000	500	10000		100	2000	10000		100
03/11/2008	LOW LEVEL, NO			1000	500	10000		100	2000	10000		100
11/11/2008	✔	✔	1000	1000	500	10000	750	100	2000	10000	1460	100
18/11/2008	✔	✔	1	1000	500	10000	0	100	2000	10000	166	100
25/11/2008	✔	✔	0	1000	500	10000	0	100	2000	10000	120	100
01/12/2008	✔	✔	0	1000	500	10000	0	100	2000	10000	77	100
09/12/2008	✔	✔	0	1000	500	10000	0	100	2000	10000	530	100
16/12/2008	✔	✔	0	1000	500	10000	0	100	2000	10000	100	100
23/12/2008	✔	✔	0	1000	500	10000	0	100	2000	10000	430	100
30/12/2008	✔	✔	0	1000	500	10000	0	100	2000	10000	28	100
06/01/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	101	100
13/01/2009	✔	✔	20	1000	500	10000	7	100	2000	10000	93	100
20/01/2009	✔	✔	23	1000	500	10000	10	100	2000	10000	126	100
27/01/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	44	100
03/02/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	23	100
10/02/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	154	100
17/02/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	101	100
24/02/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	69	100
03/03/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	23	100
10/03/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	7	100
17/03/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	24	100
24/03/2009	✔	✔	1	1000	500	10000	0	100	2000	10000	2	100
31/03/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	0	100
07/04/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	0	100
14/04/2009	NO SAMPLE			1000	500	10000		100	2000	10000		100
21/04/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	0	100
28/04/2009	NO SAMPLE			1000	500	10000		100	2000	10000		100
05/05/2009	NO SAMPLE			1000	500	10000		100	2000	10000		100
12/05/2009	✔	✔	670	1000	500	10000	25	100	2000	10000	2	100
19/05/2009	NO SAMPLE			1000	500	10000		100	2000	10000		100
26/05/2009	✔	✔	20	1000	500	10000	2	100	2000	10000	12	100
02/06/2009	✔	✔	14	1000	500	10000	14	100	2000	10000	13	100
09/06/2009	✔	✔	1	1000	500	10000	0	100	2000	10000	460	100
16/06/2009	✔	✔	18	1000	500	10000	6	100	2000	10000	230	100
23/06/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	4	100
30/06/2009	✔	✔	0	1000	500	10000	0	100	2000	10000	1	100
07/07/2009	✔	✔	140	1000	500	10000	37	100	2000	10000	100	100
14/07/2009	✔	✔	230	1000	500	10000	30	100	2000	10000	640	100
21/07/2009	✔	✔	25	1000	500	10000	18	100	2000	10000	28	100
28/07/2009	✔	✔	1	1000	500	10000	0	100	2000	10000	29	100
04/08/2009	✔	✔	5	1000	500	10000	0	100	2000	10000	48	100

					Microbiology			Inorganic chem							0.295256046	
					Protozoa			General Chemical Analysis								
TVC (22c)	TVC(37c)	TVC 37c EC Drinking	TVC 22c EC Drinking	Salmonella	Cryptosporidium	H ion conc	BSI = 5-9		Conductivity (at 20c)	TDS	Turbidity	Turb MTP	BOD	COD	N Tot (oxidised as NO3)	Ammonium (as NH4)
no/ml	no/ml	cfu no/ml (<)	cfu no/ml (<)	no/100ml	no/l	pH units	EC Bathing = 6-9		µS/cm	mg/l	NTU	<10	mg/l	mg/l	mg/l	mg/l
6600	3000	10	100	0	0	7.6	5	9	88.4	61.9	0.8	10	<3	<10	6.33	<0.01
6600	4400	10	100	\	\	7.6	5	9	83	58.1	0.6	10	\	\	5.55	<0.01
		10	100	\	\	7.7	5	9	76.2	53.3	0.4	10	\	\	5.33	<0.01
2500	5900	10	100	\	\	7.6	5	9	74.8	52.4	0.3	10	\	\	4.43	<0.01
		10	100	\	\		5	9				10	\	\		
5100	1180	10	100	\	\	7.8	5	9	77.6	54.3	0.5	10	\	\	4.25	<0.01
1960	550	10	100	\	\	7.8	5	9	68.3	47.8	0.5	10	\	\	2.19	<0.01
2700	152	10	100	\	\	7.9	5	9	80.7	56.5	0.5	10	\	\	3.75	<0.01
		10	100	\	\		5	9				10	\	\		
		10	100	\	\		5	9				10	\	\		
		10	100	\	\		5	9				10	\	\		
		10	100	\	\		5	9				10	\	\		
		10	100	\	\		5	9				10	\	\		
		10	100				5	9				10				
1720	172	10	100	0	0	8.1	5	9	72.1	50.5	1.3	10	<2	<10	3.32	<0.01
6400	50	10	100	\	\	9.9	5	9	57.8	40.5	1.6	10	\	\	1.73	0.04
303	14	10	100	\	\	10.3	5	9	149	104	1.1	10	\	\	6.99	0.21
1060	38	10	100	\	\	10.4	5	9	180	126	1.4	10	\	\	17.59	0.28
16000	80	10	100	\	\	10	5	9	85	59.5	0.9	10	\	\	3.67	0.08
18100	1860	10	100	\	\	10	5	9	65	45.5	1.6	10	\	\	2.83	0.04
2020000	59	10	100	\	\	10.1	5	9	78.7	55.1	1.9	10	\	\	3.32	0.04
9800	28000	10	100	\	\		5	9				10	\	\		
1910	280	10	100	\	\	9.4	5	9	88.5	62	1.8	10	\	\	4.66	0.03
1140	>50	10	100	\	\	8.6	5	9	96.2	67.3	1.8	10	\	\	3.47	0.16
140000	30	10	100	\	\	7.9	5	9	48.2	33.7	1.5	10	\	\	1.36	0.12
18100	40	10	100	0	0	9.9	5	9	61.4	43	0.8	10	<2	<12	1.6	0.05
300	5	10	100	\	\	9	5	9	68.4	47.9	1.4	10	\	\	4.42	0.59
28900	1020	10	100	\	\	10.2	5	9	89.7	62.8	1.8	10	\	\	3.43	0.1
26900	1200	10	100	\	\	10	5	9	93.3	65.3	2.8	10	\	\	4.07	0.05
15700	130	10	100	\	\	10	5	9	130	91	1.6	10	\	\	5.71	0.06
1640	20	10	100	\	\	10.4	5	9	261	183	2.7	10	\	\	16.13	0.1
>30000	>300	10	100	\	\	9.1	5	9	43.5	30.4	1.5	10	\	\	2.78	0.06
5900	225	10	100	\	\	9.7	5	9	80	56	1.4	10	\	\	2.58	0.05
4000	3400	10	100	\	\	9.6	5	9	89.8	62.9	0.7	10	\	\	2.06	0.02
310	>10	10	100	\	\	10.1	5	9	229	160	0.9	10	\	\	17.76	0.04
1470	1700	10	100	\	\	10	5	9	226	158	0.8	10	\	\	14.67	0.04
		10	100				5	9				10				
14300	870	10	100	\	\	8.1	5	9	84.9	59.4	1.4	10	\	\	3.51	0.19
		10	100				5	9				10				
		10	100				5	9				10				
10100	420	10	100	0	0.1	7.4	5	9	47.7	33.4	1.9	10	<2	<12	3.42	0.21
		10	100				5	9				10				
15900	3200	10	100			7.8	5	9	96.4	67.5	1.2	10			4.17	0.05
14100	4600	10	100			7	5	9	94	65.8	1	10			4.98	<0.01
>30000	220	10	100			10.1	5	9	105	73.5	7.7	10			5.77	0.37
20500	400	10	100			9.7	5	9	91.5	64	4	10			3.71	0.28
\	\	10	100			8.9	5	9	88.5	62	2.1	10			9.44	0.05
15400	2100	10	100			7.6	5	9	96.2	67.3	1.9	10			9.8	0.03
23400	4500	10	100			7.2	5	9	46.1	32.3	1.4	10			5.41	0.24
19100	2800	10	100			7.4	5	9	48.6	34	1.3	10			2.28	0.06
30000	5600	10	100			7.7	5	9	55.9	39.1	1.3	10			4.05	0.02
30000	14100	10	100			9.3	5	9	64.7	45.3	1	10			3.33	0.04
18200	8200	10	100			9.2	5	9	49.5	34.6	9.7	10			3.12	0.04

	Inorganic chem Nutrients & other Anions						Inorganic chem Metals									
Nitrate (as NO3	Nitrite (as NO2	Chloride (as Cl)	Cl MTP	Phosphorus	Silicate React (dissolved as SiO2)	Sulphate (as SO4)	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Aluminium (Al)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Copper WHO
mg/l	mg/l	mg/l	<2	µg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	
6.33	<0.01	5	2	<50	0.97	5.3	10	0.37	2.4	4.3	80.2	9	<2	218	2000
5.55	<0.01	5	2	\	0.9	\	\	\	\	\	\	\	\	\	
5.33	<0.01	4	2	\	0.81	\	\	\	\	\	\	\	\	\	
4.43	<0.01	4	2	\	0.8	\	\	\	\	\	\	\	\	\	
			2	\		\	\	\	\	\	\	\	\	\	
4.25	<0.01	4	2	\	0.77	\	\	\	\	\	\	\	\	\	
2.19	<0.01	4	2	\	0.8	\	\	\	\	\	\	\	\	\	
3.75	<0.01	4	2	\	0.97	\	\	\	\	\	\	\	\	\	
			2	\		\	\	\	\	\	\	\	\	\	
			2	\		\	\	\	\	\	\	\	\	\	
			2	\		\	\	\	\	\	\	\	\	\	
			2	\		\	\	\	\	\	\	\	\	\	
			2	\		\	\	\	\	\	\	\	\	\	
			2												
3.32	<0.01	4	2	<50	0.87	<2.5	10	0.58	1.2	2.8	108	27.4	3.18	237	2000
1.67	0.05		2	\	0.63	\	\	\	\	\	\	\	\	\	
6.8	0.14	6	2	\	2.2	\	\	\	\	\	\	\	\	\	
17.36	0.17	9	2	\	2.8	\	\	\	\	\	\	\	\	\	
3.59	0.06	7	2	\	0.74	\	\	\	\	\	\	\	\	\	
2.78	0.03	5	2	\	0.75	\	\	\	\	\	\	\	\	\	
3.26	0.04	5	2	\	0.91	\	\	\	\	\	\	\	\	\	
			2	\		\	\	\	\	\	\	\	\	\	
4.57	0.06	7	2	\	2.3	\	\	\	\	\	\	\	\	\	
3.37	0.07	10	2	\	1.2	\	\	\	\	\	\	\	\	\	
1.32	0.03	7	2	\	0.35	\	\	\	\	\	\	\	\	\	
1.55	0.03	7	2	<15	0.53	3.4	5.7	0.36	1	4.3	101	19.6	<2	290	2000
4.32	0.07	6	2	\	0.58	\	\	\	\	\	\	\	\	\	
3.35	0.06	7	2	\	1.1	\	\	\	\	\	\	\	\	\	
3.95	0.09	7	2	\	1.2	\	\	\	\	\	\	\	\	\	
5.48	0.17	13	2	\	1.9	\	\	\	\	\	\	\	\	\	
15.83	0.22	28	2	\	4	\	\	\	\	\	\	\	\	\	
2.72	0.05	3	2	\	0.49	\	\	\	\	\	\	\	\	\	
2.52	0.05	8	2	\	0.74	\	\	\	\	\	\	\	\	\	
2.03	0.02	10	2	\	0.87	\	\	\	\	\	\	\	\	\	
17.74	0.01	26	2	\	3.1	\	\	\	\	\	\	\	\	\	
14.64	0.02	27	2	\	2.3										
			2												
3.51	<0.01	8	2	\	1.7	\	\	\	\	\	\	\	\	\	
			2												
			2												
3.31	0.08	3	2	19	0.48	<2.5	5.2	<0.3	0.79	2.4	52.3	15.6	3.22	117	2000
			2												
3.9	0.2	12	2		1.1										
4.98	<0.01	10	2		1.1										
5.69	0.06	6	2		1.9										
3.49	0.16	5	2		1.8										
9.26	0.14	5	2		1.8										
9.57	0.16	6	2		1.7										
5.27	0.1		2		0.72										
2.28	0.01	2	2		0.69										
4.05	0.01	5	2		0.76										
3.33	0.01	4	2		1										
3.12	0.01	2	2		0.83										

						Organic Chem	Organic chem PAHs					
Zinc (Zn)	Lead (Pb)	Lead	Cadmium (Cd)	Chromium (Cr)	Nickel (Ni)	Oil & Grease	Benzo (a)	Benzo (b)	Benzo(ghi)	Benzo (k)	Indeno (123-cd)	PAHs
µg/l	µg/l	WHO	µg/l	µg/l	µg/l	mg/l	ng/l	µg/l	µg/l	µg/l	µg/l	µg/l
193	25.5	10	<0.4	<0.5	<1.5	<1	<1	<0.001	<0.002	<0.001	<0.003	0
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393	64.4	10	<0.4	<0.5	1.68	<1	<1	<0.001	<0.002	<0.001	<0.003	0
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480	40	10	<0.4	<0.5	<1.5	<1	<1	<0.001	<0.002	<0.001	<0.003	0
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379	1.52	10	<0.4	<0.5	<1.5	<1	<1	<0.001	<0.001	<0.001	<0.001	0

http://www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=IDEVONEX3
Whipton Weather Station

Date	TemperatureHighC	TemperatureAvgC	TemperatureLowC	DewpointHighC	DewpointAvgC	DewpointLowC	HumidityHigh	HumidityAvg	HumidityLow	PressureMaxhPa	PressureMinhPa	WindSpeedMaxKMH	WindSpeedAvgKMH	GustSpeedMaxKMH	PrecipitationSumCM	PPT (mm)	Events > 5mm
21/07/2008	22	16	11	13	10	9	90	70	52	1027	1013	26	3	26	0	0	0
22/07/2008	24	18	12	17	13	0	90	75	42	1027	1024	13	2	13	0	0	0
23/07/2008	24	17	13	17	13	3	92	77	46	1025	1018	13	1	13	0	0	0
24/07/2008	29	21	16	17	13	6	82	62	44	1019	1008	21	1	21	0	0	0
25/07/2008	24	19	16	18	15	5	84	75	40	1013	1006	17	1	17	0.05	0.5	0
26/07/2008	25	18	13	16	14	5	92	76	53	1016	1013	17	1	17	0	0	0
27/07/2008	17	17	17	13	13	13	78	78	78	1015	1015	0	0	0	0	0	0
28/07/2008	26	19	13	18	14	7	88	74	49	1016	1009	26	2	26	0.05	0.5	0
29/07/2008	20	17	15	17	14	13	93	87	79	1013	1007	26	4	26	1.93	19.3	1
30/07/2008	21	17	16	17	15	6	93	88	77	1014	1012	98	6	98	0.05	0.5	0
31/07/2008	22	17	14	17	15	13	94	89	83	1013	1005	24	4	24	1.09	10.9	1
01/08/2008	21	14	13	13	12	4	93	93	93	1011	1006	19	0	19	0.15	1.5	0
02/08/2008	24	18	16	16	15	4	92	82	48	1013	1010	23	1	23	0	0	0
03/08/2008	19	17	13	17	14	2	91	84	43	1012	1007	12	1	13	0.79	7.9	1
04/08/2008	19	15	12	14	12	2	94	87	48	1013	1008	10	1	10	0.05	0.5	0
05/08/2008	19	17	15	17	15	7	94	89	48	1013	1010	23	4	23	0.1	1	0
06/08/2008	21	18	16	18	16	6	94	89	78	1012	1006	19	4	19	0.05	0.5	0
07/08/2008	21	17	14	17	15	6	93	86	73	1006	1004	20	2	21	0.15	1.5	0
08/08/2008	23	19	15	15	14	2	88	73	43	1014	1006	95	4	95	0	0	0
09/08/2008	23	23	23	15	15	15	60	60	60	1014	1014	8	5	8	0	0	0
12/08/2008	23	14	13	15	10	10	80	79	60	1014	995	7	1	8	0	0	0
13/08/2008	17	14	12	12	11	1	88	82	43	1009	995	17	2	18	0.15	1.5	0
14/08/2008	20	15	9	14	11	8	92	78	58	1014	1009	10	0	10	0.05	0.5	0
15/08/2008	20	15	7	14	11	5	92	78	60	1016	1010	16	2	16	0	0	0
16/08/2008	18	15	14	14	13	12	94	90	83	1010	1001	28	6	28	0.94	9.4	1
17/08/2008	20	15	10	14	12	2	94	84	34	1005	1001	22	3	22	2.08	20.8	1
18/08/2008	19	15	13	16	14	12	95	89	79	1002	998	25	5	25	0.46	4.6	0
19/08/2008	20	17	14	15	13	11	86	80	69	1007	1000	15	2	15	0	0	0
20/08/2008	20	16	14	15	13	12	90	83	69	1011	1007	17	2	18	0.1	1	0
21/08/2008	23	17	13	15	13	12	92	79	54	1026	1011	25	1	25	0.05	0.5	0
22/08/2008	20	16	13	13	11	9	92	76	52	1029	1025	39	6	39	0	0	0
23/08/2008	20	14	8	14	11	7	93	81	60	1029	1021	37	3	37	0.15	1.5	0
24/08/2008	22	16	14	14	13	11	94	82	63	1023	1017	31	4	31	0.66	6.6	1
25/08/2008	24	18	15	18	14	13	90	80	66	1029	1022	28	3	29	0	0	0
26/08/2008	21	17	16	16	14	13	86	80	70	1034	1029	24	1	24	0	0	0
27/08/2008	21	17	16	16	14	13	87	80	69	1034	1012	24	2	24	0	0	0
28/08/2008	19	17	15	16	14	13	90	85	77	1024	1022	23	2	23	0	0	0
29/08/2008	22	18	15	17	15	5	92	83	69	1022	1018	28	2	29	0	0	0
30/08/2008	23	18	16	18	15	4	90	83	70	1018	1012	30	3	30	0.1	1	0
31/08/2008	19	16	12	16	14	9	93	87	76	1014	1009	33	2	34	0.74	7.4	1
01/09/2008	20	12	11	10	10	4	88	88	87	1014	1006	46	0	47	0.46	4.6	0
02/09/2008	20	15	11	14	11	1	94	82	33	1006	1001	41	4	42	0.46	4.6	0
03/09/2008	20	14	10	12	10	0	90	78	40	1005	1000	32	5	32	0	0	0
04/09/2008	17	14	13	13	11	10	90	82	72	1001	998	30	4	30	0.25	2.5	0
05/09/2008	17	14	12	15	13	11	94	93	88	998	983	45	9	45	3	30	1
06/09/2008	18	14	11	15	12	10	94	90	78	1002	988	36	4	37	0.3	3	0
07/09/2008	18	14	10	12	11	8	88	80	64	1013	1002	34	5	34	0	0	0
08/09/2008	17	13	8	12	10	1	92	84	41	1015	1012	27	2	27	0.41	4.1	0
09/09/2008	19	15	12	16	14	11	95	89	77	1012	1005	38	4	38	1.7	17	1
10/09/2008	20	16	13	16	14	12	93	86	73	1011	1004	45	6	45	0.1	1	0
11/09/2008	17	14	11	15	12	9	94	89	75	1010	1003	32	4	32	0.41	4.1	0
12/09/2008	19	14	8	13	10	7	94	82	63	1016	1010	23	2	23	0	0	0
13/09/2008	20	15	11	15	12	9	94	82	69	1023	1016	24	3	24	0	0	0
14/09/2008	21	14	7	15	11	6	91	83	69	1025	1023	26	2	26	0	0	0
15/09/2008	17	14	12	14	12	3	93	85	72	1024	1023	20	1	21	0	0	0
16/09/2008	17	13	8	12	9	7	93	80	65	1024	1022	17	0	18	0	0	0
17/09/2008	16	12	9	12	9	8	88	81	71	1023	1021	32	2	32	0	0	0
18/09/2008	16	10	6	11	7	5	93	84	62	1025	1023	15	0	15	0	0	0
19/09/2008	19	11	7	12	8	5	92	84	61	1031	1025	10	0	10	0	0	0
20/09/2008	20	12	6	13	9	1	93	80	33	1031	1028	20	1	21	0	0	0
21/09/2008	18	12	7	13	10	5	92	85	66	1026	1025	20	1	21	0	0	0
22/09/2008	18	11	9	12	8	7	88	85	66	1026	1025	28	1	28	0	0	0
23/09/2008	18	14	11	11	10	8	87	77	62	1027	1025	34	7	34	0	0	0
24/09/2008	18	14	10	12	10	7	86	78	68	1029	1013	37	6	37	0	0	0
25/09/2008	18	15	12	13	11	0	88	79	31	1034	1029	13	2	13	0	0	0
26/09/2008	18	13	8	11	9	6	90	79	59	1035	1033	15	1	15	0	0	0
27/09/2008	17	12	6	13	9	5	92	83	64	1033	1029	10	0	10	0	0	0
28/09/2008	17	11	4	12	8	-4	93	83	61	1029	1024	17	1	17	0	0	0
29/09/2008	16	12	8	10	9	6	90	80	59	1024	1017	19	2	19	0	0	0

Date	TemperatureHighC	TemperatureAvgC	TemperatureLowC	DewpointHighC	DewpointAvgC	DewpointLowC	HumidityHigh	HumidityAvg	HumidityLow	PressureMaxhPa	PressureMinhPa	WindSpeedMaxKMH	WindSpeedAvgKMH	GustSpeedMaxKMH	PrecipitationSumCM	PPT (mm)	Events > 5mm
30/09/2008	15	13	12	12	11	10	91	87	78	1017	1005	17	2	17	0.25	2.5	0
01/10/2008	15	14	13	12	12	0	89	88	88	1007	1002	26	1	26	0.46	4.6	0
02/10/2008	14	9	7	8	6	4	91	81	59	1008	1004	21	2	21	1.5	15	1
03/10/2008	12	9	5	7	4	2	87	74	59	1022	1008	26	5	26	8.18	81.8	1
04/10/2008	15	10	3	13	8	1	90	87	79	1021	1001	23	3	23	0.61	6.1	1
05/10/2008	18	14	10	16	12	9	93	89	83	1008	992	22	3	23	0.41	4.1	0
06/10/2008	16	13	9	14	11	8	93	89	83	1011	1007	21	2	21	0.15	1.5	0
07/10/2008	18	14	10	16	13	9	95	92	81	1012	1000	34	4	34	1.45	14.5	1
08/10/2008	17	11	7	13	8	6	94	86	64	1028	1012	15	0	15	0.05	0.5	0
09/10/2008	17	10	4	14	8	3	94	87	72	1032	1028	23	1	23	0	0	0
10/10/2008	18	13	10	13	10	8	92	84	72	1032	1027	23	3	23	0	0	0
11/10/2008	17	12	6	14	10	4	94	88	78	1027	1024	17	1	17	0	0	0
12/10/2008	19	14	11	16	12	10	94	90	79	1025	1019	18	1	18	0	0	0
13/10/2008	18	14	12	14	12	10	95	87	72	1022	1016	17	0	17	0	0	0
14/10/2008	18	14	11	14	12	10	92	87	76	1022	1015	13	1	13	0	0	0
15/10/2008	15	13	10	13	11	9	92	87	76	1016	1011	24	2	24	0.05	0.5	0
16/10/2008	14	10	5	10	7	3	92	84	65	1022	1014	19	2	19	0.2	2	0
17/10/2008	14	8	3	11	6	2	93	87	76	1022	1020	12	0	12	0	0	0
18/10/2008	14	9	3	11	7	2	93	85	73	1021	1019	13	0	13	0	0	0
19/10/2008	16	12	9	12	10	7	90	84	69	1020	1012	23	3	23	0	0	0
20/10/2008	16	13	9	14	11	8	94	89	82	1012	1005	28	3	28	1.8	18	1
21/10/2008	12	8	4	8	6	2	94	86	68	1019	1007	15	1	15	0	0	0
22/10/2008	13	7	3	10	5	2	94	89	76	1026	1019	12	0	12	0.41	4.1	0
23/10/2008	15	12	6	12	9	4	93	88	78	1026	1016	31	3	31	0.1	1	0
24/10/2008	13	10	4	12	7	2	91	82	62	1031	1015	16	1	16	0	0	0
25/10/2008	14	8	1	12	6	0	93	87	79	1031	1021	30	2	30	0	0	0
26/10/2008	15	12	6	13	10	5	93	89	84	1021	1014	20	2	21	0.3	3	0
27/10/2008	12	6	4	7	5	-3	93	90	80	1014	1011	13	1	13	0.46	4.6	0
28/10/2008	9	4	1	6	3	0	93	90	77	1014	1010	19	1	19	0.61	6.1	1
29/10/2008	9	4	0	6	2	-2	93	87	72	1015	990	24	2	24	0.36	3.6	0
30/10/2008	8	6	4	6	4	2	94	88	81	1004	986	25	4	26	0.25	2.5	0
31/10/2008	10	5	2	4	2	0	89	82	71	1011	1004	21	3	21	0	0	0
01/11/2008	8	5	2	6	3	1	91	86	79	1010	1006	28	6	29	0	0	0
02/11/2008	12	8	6	9	5	5	89	85	83	1017	1010	26	6	26	0.15	1.5	0
03/11/2008	12	9	8	8	7	6	91	85	79	1017	1014	28	5	29	0	0	0
04/11/2008	12	9	5	10	8	4	92	89	83	1020	1016	19	2	19	0	0	0
05/11/2008	13	10	6	9	8	5	93	87	78	1020	1018	15	2	15	0	0	0
06/11/2008	14	10	8	10	8	7	92	88	81	1018	1004	23	2	23	0	0	0
07/11/2008	14	9	5	10	7	4	93	86	72	1009	1003	22	2	23	0	0	0
08/11/2008	16	11	6	11	9	5	93	89	83	1008	1000	48	6	48	0.74	7.4	1
09/11/2008	12	9	4	9	7	3	91	87	81	1011	1003	30	5	31	0.15	1.5	0
10/11/2008	11	8	6	8	6	5	94	90	81	1007	1001	20	2	21	0	0	0
11/11/2008	13	7	4	8	5	3	94	88	74	1014	1002	19	3	19	0.05	0.5	0
12/11/2008	11	6	3	9	4	1	94	90	78	1025	1014	16	1	16	0.05	0.5	0
13/11/2008	11	8	2	11	7	1	95	94	92	1025	1022	14	1	14	0.74	7.4	1
14/11/2008	15	11	10	11	10	9	95	92	85	1028	1025	15	2	15	0.05	0.5	0
15/11/2008	14	12	10	12	10	9	92	89	83	1031	1027	18	2	18	0	0	0
16/11/2008	14	11	9	12	10	8	93	91	85	1035	1031	17	2	17	0.05	0.5	0
17/11/2008	12	11	9	11	9	8	94	91	85	1035	1015	17	2	17	0.1	1	0
18/11/2008	15	10	8	10	8	6	92	85	75	1026	1014	23	4	23	0	0	0
19/11/2008	15	10	8	9	8	6	92	86	70	1026	1022	25	6	25	0	0	0
20/11/2008	14	12	10	11	10	8	93	87	79	1023	1019	24	6	24	0	0	0
21/11/2008	12	10	7	11	7	3	93	80	68	1022	1016	27	8	27	0.15	1.5	0
22/11/2008	13	8	6	10	5	2	88	80	74	1022	1019	22	4	23	0	0	0
23/11/2008	12	7	5	9	4	2	93	82	74	1019	993	30	6	31	0.3	3	0
24/11/2008	9	6	3	4	2	0	89	76	65	1018	991	33	6	34	0	0	0
25/11/2008	7	4	1	2	0	-2	87	78	66	1030	1018	23	2	23	0	0	0
26/11/2008	12	7	0	10	5	-2	91	88	85	1030	1024	12	0	12	0	0	0
27/11/2008	12	8	3	9	6	2	94	89	79	1024	1005	21	2	21	0.3	3	0
28/11/2008	6	2	-2	5	1	-3	94	92	89	1005	995	6	0	6	0	0	0
29/11/2008	4	2	-2	2	0	-3	94	91	85	995	992	23	4	23	0.56	5.6	1
30/11/2008	5	3	1	2	0	-8	91	81	71	1003	994	26	6	26	0.05	0.5	0
01/12/2008	5	2	-1	2	-1	-3	92	81	54	1013	1003	15	2	15	0	0	0
02/12/2008	6	3	-1	5	2	-2	94	91	83	1012	997	17	1	17	1.45	14.5	1
03/12/2008	4	2	0	3	1	-2	94	92	89	1005	996	12	1	13	0.1	1	0
04/12/2008	12	7	3	10	5	2	95	90	81	998	981	30	5	31	0.94	9.4	1
05/12/2008	8	6	4	6	5	3	93	89	81	1003	980	25	5	25	0.79	7.9	1
06/12/2008	7	4	-1	4	2	-2	93	89	84	1024	1003	20	1	20	0	0	0
07/12/2008	5	0	-3	4	-1	-4	94	93	92	1029	1024	0	0	0	0.05	0.5	0
08/12/2008	6	2	-2	6	2	-3	95	94	93	1028	1017	22	0	23	0.3	3	0
09/12/2008	7	4	2	5	2	0	94	91	81	1025	1020	29	3	29	0.3	3	0

Date	TemperatureHighC	TemperatureAvgC	TemperatureLowC	DewpointHighC	DewpointAvgC	DewpointLowC	HumidityHigh	HumidityAvg	HumidityLow	PressureMaxhPa	PressureMinhPa	WindSpeedMaxKMH	WindSpeedAvgKMH	GustSpeedMaxKMH	PrecipitationSumCM	PPT (mm)	Events > 5mm
10/12/2008	6	3	0	4	1	-1	92	90	86	1025	1015	17	2	17	0	0	0
11/12/2008	3	0	-3	2	-2	-4	94	93	92	1015	1012	0	0	0	0.05	0.5	0
12/12/2008	12	5	0	8	4	-1	95	93	85	1014	994	41	5	42	0.56	5.6	1
13/12/2008	10	6	1	9	5	0	94	94	92	994	987	35	2	35	3.1	31	1
14/12/2008	6	3	1	4	2	0	94	91	87	1012	991	15	1	15	0	0	0
15/12/2008	6	3	-1	4	1	-2	93	89	86	1021	1012	22	1	22	0	0	0
16/12/2008	9	3	-2	8	2	-2	95	94	93	1020	1011	18	0	18	0.05	0.5	0
17/12/2008	8	5	3	6	4	2	94	91	83	1020	1012	17	0	17	0	0	0
18/12/2008	12	10	7	9	8	5	94	87	77	1022	1019	20	1	21	0	0	0
19/12/2008	11	7	2	9	5	1	93	88	83	1028	1022	19	1	19	0	0	0
20/12/2008	14	11	10	10	9	7	91	86	80	1033	1024	18	3	18	0	0	0
21/12/2008	15	11	9	8	8	7	88	82	72	1035	1032	18	2	18	0	0	0
22/12/2008	11	9	8	9	8	7	91	89	85	1036	1035	9	0	10	0	0	0
23/12/2008	9	9	8	8	7	6	92	90	88	1036	1034	20	1	20	0	0	0
24/12/2008	9	8	7	7	6	4	90	86	81	1036	1033	10	0	10	0	0	0
25/12/2008	7	6	5	5	3	2	88	81	76	1035	1032	8	0	8	0	0	0
26/12/2008	5	3	0	2	0	-3	84	78	68	1036	1033	16	1	16	0	0	0
27/12/2008	3	0	-2	0	-2	-4	88	84	73	1035	1031	15	1	15	0	0	0
28/12/2008	7	1	-2	1	-2	-4	90	85	65	1031	1025	13	1	13	0	0	0
29/12/2008	2	2	1	0	-1	-2	83	81	80	1028	1026	14	1	14	0	0	0
30/12/2008	5	1	-3	2	-1	-4	91	86	80	1030	1028	8	0	9	0	0	0
31/12/2008	0	-2	-5	-1	-3	-6	93	91	89	1029	1027	11	0	11	0	0	0
01/01/2009	2	1	-1	0	-1	-2	90	87	84	1029	1028	13	0	13	0	0	0
02/01/2009	5	2	-2	2	-1	-3	90	84	76	1030	1028	17	1	17	0	0	0
03/01/2009	1	-1	-4	-2	-3	-6	89	84	79	1030	1028	13	0	13	0	0	0
04/01/2009	3	1	-2	1	-2	-4	91	85	81	1028	1020	6	0	6	0	0	0
05/01/2009	4	1	-2	1	-2	-5	92	84	73	1027	1019	21	1	21	0	0	0
06/01/2009	1	-3	-6	-4	-6	-8	85	78	63	1029	1027	15	0	15	0	0	0
07/01/2009	2	-2	-9	-1	-4	-10	89	86	81	1030	1027	10	0	10	0	0	0
08/01/2009	4	2	0	2	0	-2	90	87	83	1030	1027	6	0	6	0	0	0
09/01/2009	3	1	-2	1	-1	-4	91	88	84	1028	1027	4	0	4	0	0	0
10/01/2009	6	1	-4	3	0	-5	93	90	85	1028	1024	19	1	19	0	0	0
11/01/2009	13	8	3	8	6	1	92	87	83	1024	1016	35	8	35	0	0	0
12/01/2009	12	10	8	10	8	6	93	91	88	1016	1006	29	4	29	0.1	1	0
13/01/2009	9	6	2	7	4	1	94	89	80	1013	1008	19	0	19	0.05	0.5	0
14/01/2009	12	4	-1	9	3	-2	94	93	85	1015	1009	22	3	23	0.05	0.5	0
15/01/2009	9	8	7	7	6	6	94	90	84	1011	1007	34	10	34	0.36	3.6	0
16/01/2009	12	8	7	11	7	6	95	94	88	1012	1007	30	5	30	0.84	8.4	1
17/01/2009	13	8	5	8	6	4	94	89	72	1011	993	47	5	47	0.99	9.9	1
18/01/2009	8	5	3	4	3	1	93	88	75	1000	992	21	2	21	0.2	2	0
19/01/2009	9	4	1	5	3	0	93	91	87	993	979	36	3	36	0.84	8.4	1
20/01/2009	6	2	-1	4	1	-2	93	89	81	998	986	18	0	18	0.1	1	0
21/01/2009	10	4	-2	9	3	-3	94	93	90	1004	988	28	4	28	0.36	3.6	0
22/01/2009	13	8	6	9	6	4	94	88	73	989	973	32	3	32	0.99	9.9	1
23/01/2009	6	5	1	5	3	0	94	90	77	987	970	26	3	26	0.56	5.6	1
24/01/2009	8	5	2	7	3	0	93	88	79	994	984	35	3	35	0.46	4.6	0
25/01/2009	8	6	4	7	5	3	94	91	87	987	980	39	4	39	0.66	6.6	1
26/01/2009	8	5	2	6	3	0	94	91	88	1010	987	22	2	23	0.15	1.5	0
27/01/2009	12	5	0	8	4	-1	95	94	93	1012	1010	21	2	21	0.61	6.1	1
28/01/2009	9	8	6	8	7	4	95	93	91	1015	1011	11	0	12	0.46	4.6	0
29/01/2009	10	7	6	6	6	4	94	93	89	1013	1011	23	5	23	0.15	1.5	0
30/01/2009	10	7	6	6	5	4	94	92	89	1012	1007	23	4	23	1.65	16.5	1
31/01/2009	7	6	5	5	4	2	89	87	84	1008	1006	32	2	32	0	0	0
01/02/2009	5	1	-2	2	-3	-7	85	75	61	1010	1006	21	2	21	0	0	0
02/02/2009	3	-2	-3	-2	-4	-6	89	82	70	1006	993	26	4	26	0	0	0
03/02/2009	3	0	-5	2	-2	-6	92	89	85	994	991	25	2	25	0.36	3.6	0
04/02/2009	9	4	1	4	1	-1	93	86	62	993	987	24	2	24	0.61	6.1	1
05/02/2009	3	2	0	2	0	-1	93	91	90	989	985	17	2	18	0.41	4.1	0
06/02/2009	5	1	0	2	-1	-2	93	88	77	996	987	37	5	37	0.99	9.9	1
07/02/2009	5	2	0	2	0	-2	91	87	77	1005	996	24	3	24	0.05	0.5	0
08/02/2009	5	2	-1	4	1	-2	93	91	87	1005	1000	19	1	19	0.05	0.5	0
09/02/2009	9	4	2	6	3	1	93	92	85	1003	978	27	3	27	2.54	25.4	1
10/02/2009	8	4	0	4	2	-1	93	85	74	1016	984	24	4	24	0.05	0.5	0
11/02/2009	8	3	-1	6	1	-3	93	89	73	1024	1016	13	0	14	0	0	0
12/02/2009	8	4	-2	6	1	-3	92	85	71	1029	1024	24	1	24	0	0	0
13/02/2009	8	6	5	6	5	3	92	90	86	1027	1022	18	2	18	0	0	0
14/02/2009	8	5	4	4	2	1	87	83	74	1030	1027	13	1	14	0	0	0
15/02/2009	11	6	4	7	4	2	92	86	73	1030	1028	22	1	23	0.05	0.5	0
16/02/2009	10	7	4	7	5	3	93	88	76	1029	1028	17	2	17	0	0	0
17/02/2009	13	8	7	6	6	4	90	83	68	1029	1028	23	4	23	0.05	0.5	0
18/02/2009	11	9	7	9	7	5	91	87	81	1029	1026	16	1	16	0.1	1	0

Date	TemperatureHighC	TemperatureAvgC	TemperatureLowC	DewpointHighC	DewpointAvgC	DewpointLowC	HumidityHigh	HumidityAvg	HumidityLow	PressureMaxhPa	PressureMinhPa	WindSpeedMaxKMH	WindSpeedAvgKMH	GustSpeedMaxKMH	PrecipitationSumCM	PPT (mm)	Events > 5mm
19/02/2009	10	8	6	8	6	4	92	89	81	1030	1026	13	1	13	0.15	1.5	0
20/02/2009	11	7	2	8	5	1	93	89	78	1035	1030	11	0	11	0	0	0
21/02/2009	12	6	3	7	4	1	93	87	77	1035	1033	21	2	21	0	0	0
22/02/2009	12	8	4	8	6	3	92	85	74	1033	1029	34	4	34	0	0	0
23/02/2009	11	8	4	7	5	3	91	84	72	1029	1026	23	2	23	0	0	0
24/02/2009	11	8	4	9	6	3	92	88	82	1030	1027	9	0	10	0	0	0
25/02/2009	10	8	6	7	6	4	87	84	78	1031	1028	16	1	16	0	0	0
26/02/2009	11	8	6	7	5	4	90	82	66	1029	1024	27	2	27	0	0	0
27/02/2009	11	9	7	8	6	5	90	83	74	1024	1019	23	2	23	0	0	0
28/02/2009	11	8	7	7	5	4	87	81	72	1019	1008	27	1	27	0	0	0
01/03/2009	14	7	4	7	4	2	91	81	64	1015	1007	31	3	32	0	0	0
02/03/2009	12	7	2	7	4	0	93	84	66	1019	1015	23	2	23	0	0	0
03/03/2009	12	8	3	9	6	2	92	89	82	1016	985	50	4	50	1.65	16.5	1
04/03/2009	7	3	1	5	1	0	93	91	83	985	981	21	1	21	0.66	6.6	1
05/03/2009	7	3	0	3	1	-1	93	87	74	1005	980	30	5	31	0.99	9.9	1
06/03/2009	11	5	-2	7	3	-3	93	87	71	1010	1005	16	1	19	0	0	0
07/03/2009	13	9	4	10	7	3	92	86	74	1013	1006	32	2	32	0.05	0.5	0
08/03/2009	12	7	3	9	3	1	90	79	62	1010	1004	49	8	50	0.36	3.6	0
09/03/2009	11	7	4	5	3	1	85	76	58	1016	1010	41	6	41	0	0	0
10/03/2009	13	9	6	8	7	4	92	82	69	1021	1007	49	6	49	0.46	4.6	0
11/03/2009	13	9	6	11	8	5	93	90	82	1024	1021	15	1	15	0	0	0
12/03/2009	15	11	9	10	8	6	90	82	69	1024	1022	29	4	29	0	0	0
13/03/2009	12	9	8	9	7	6	89	84	73	1023	1013	38	5	39	0	0	0
14/03/2009	13	10	7	8	6	4	88	78	62	1028	1013	42	6	42	0	0	0
15/03/2009	15	8	2	8	5	1	92	80	61	1033	1028	23	1	23	0	0	0
16/03/2009	15	7	1	9	4	0	91	83	60	1033	1031	21	2	21	0	0	0
17/03/2009	15	7	1	10	5	0	93	83	68	1034	1032	25	2	26	0	0	0
18/03/2009	15	9	4	10	6	2	91	85	73	1034	1028	19	1	21	0	0	0
19/03/2009	16	7	0	9	2	-1	93	75	47	1030	1027	27	1	27	0	0	0
20/03/2009	12	7	1	8	4	-1	89	80	62	1031	1030	20	2	21	0	0	0
21/03/2009	15	6	-2	7	3	-3	91	79	53	1033	1030	28	2	28	0	0	0
22/03/2009	16	9	3	8	5	0	90	77	60	1035	1030	31	4	32	0	0	0
23/03/2009	13	9	6	8	6	2	90	80	67	1030	1018	40	8	40	0	0	0
24/03/2009	11	8	4	6	3	1	84	72	54	1023	1012	33	6	34	0	0	0
25/03/2009	11	9	7	7	5	4	89	76	65	1012	1008	45	8	45	0	0	0
26/03/2009	16	9	6	10	6	2	87	79	61	1012	1002	43	6	43	0.05	0.5	0
27/03/2009	11	7	4	7	3	1	90	81	68	1005	996	27	3	27	0.3	3	0
28/03/2009	11	7	4	6	3	1	91	80	64	1013	995	43	6	43	0.1	1	0
29/03/2009	13	6	2	3	1	-1	84	71	48	1016	1013	24	2	24	0	0	0
30/03/2009	13	6	0	8	3	-2	90	81	72	1022	1016	20	2	21	0	0	0
31/03/2009	15	10	8	10	7	5	88	79	65	1024	1023	15	0	15	0	0	0
01/04/2009	17	9	9	6	6	4	80	80	79	1023	1021	18	0	19	0	0	0
02/04/2009	15	10	5	9	6	3	88	79	67	1022	1018	19	1	19	0	0	0
03/04/2009	14	9	3	10	6	2	92	85	75	1019	1015	26	3	26	0	0	0
04/04/2009	16	10	6	8	6	4	92	80	57	1025	1015	27	3	27	0.2	2	0
05/04/2009	14	9	5	8	6	3	91	81	60	1025	1016	24	3	24	0	0	0
06/04/2009	13	9	7	10	7	6	92	87	73	1016	1003	38	5	39	0.05	0.5	0
07/04/2009	16	9	4	9	6	3	92	82	64	1008	1001	45	6	45	0.3	3	0
08/04/2009	17	11	6	9	7	4	92	77	55	1010	1000	40	4	40	0.15	1.5	0
09/04/2009	12	11	10	11	9	8	91	89	82	1009	1001	43	8	43	0.05	0.5	0
10/04/2009	16	10	7	11	8	4	93	84	66	1006	1000	26	3	26	0	0	0
11/04/2009	15	9	2	7	4	1	91	74	45	1013	1006	23	2	23	0	0	0
12/04/2009	16	9	4	9	5	2	92	75	53	1016	1013	25	2	25	0	0	0
13/04/2009	17	8	0	8	5	-1	90	80	64	1014	1007	36	5	36	0	0	0
14/04/2009	16	11	8	11	9	7	92	85	75	1009	1007	23	2	23	0	0	0
15/04/2009	16	12	8	12	9	6	91	84	73	1007	1001	23	2	24	0	0	0
16/04/2009	15	11	7	11	9	6	91	84	72	1009	1001	23	3	23	0	0	0
17/04/2009	17	10	4	12	7	3	92	84	63	1014	1009	15	0	16	0	0	0
18/04/2009	15	11	7	9	7	5	91	79	63	1022	1014	18	2	19	0	0	0
19/04/2009	18	11	5	10	6	3	89	75	58	1026	1022	22	2	23	0	0	0
20/04/2009	21	13	5	12	8	3	90	73	49	1028	1026	22	2	23	0	0	0
21/04/2009	17	12	7	10	8	5	90	76	56	1030	1028	27	3	27	0	0	0
22/04/2009	18	12	6	12	9	5	92	81	67	1029	1024	26	2	26	0	0	0
23/04/2009	16	11	6	11	8	5	92	83	70	1024	1017	27	3	27	0	0	0
24/04/2009	19	13	9	11	9	6	91	77	65	1017	1003	38	5	39	0	0	0
25/04/2009	14	11	7	9	7	5	89	77	59	1007	1001	40	8	56	0	0	0
26/04/2009	15	11	7	11	8	5	90	82	71	1007	1004	40	4	40	0	0	0
27/04/2009	14	9	4	10	6	2	92	84	63	1004	995	32	2	32	0	0	0
28/04/2009	14	8	1	9	4	0	92	78	53	1005	998	23	2	23	0	0	0
29/04/2009	16	10	4	10	7	3	92	83	67	1011	1005	29	4	29	0.15	1.5	0
30/04/2009	14	11	8	12	10	6	93	91	86	1021	1009	34	4	34	0.89	8.9	1

Date	TemperatureHighC	TemperatureAvgC	TemperatureLowC	DewpointHighC	DewpointAvgC	DewpointLowC	HumidityHigh	HumidityAvg	HumidityLow	PressureMaxhPa	PressureMinhPa	WindSpeedMaxKMH	WindSpeedAvgKMH	GustSpeedMaxKMH	PrecipitationSumCM	PPT (mm)	Events > 5mm
01/05/2009	18	7	7	6	6	5	92	92	92	1027	1021	27	0	27	0.05	0.5	0
02/05/2009	19	12	5	11	7	-4	92	73	53	1030	1027	20	1	21	0	0	0
03/05/2009	15	11	7	8	6	3	89	71	54	1032	1028	33	4	33	0.1	1	0
04/05/2009	15	10	3	9	7	2	90	81	63	1031	1026	27	2	27	0	0	0
05/05/2009	20	14	11	13	10	9	91	79	63	1026	1022	31	3	32	0	0	0
06/05/2009	20	14	11	14	10	8	87	77	63	1022	1017	27	3	29	0	0	0
07/05/2009	17	13	10	11	9	-2	87	79	40	1017	1010	23	2	23	0.05	0.5	0
08/05/2009	17	12	8	8	6	4	83	69	52	1018	1008	38	4	39	0.05	0.5	0
09/05/2009	18	12	7	10	7	4	87	72	55	1018	1015	22	1	23	0	0	0
10/05/2009	20	13	3	11	7	2	90	72	53	1019	1016	18	1	19	0	0	0
11/05/2009	19	14	10	9	6	4	70	60	51	1020	1017	38	5	39	0	0	0
12/05/2009	18	12	6	9	6	2	79	67	51	1020	1017	32	4	32	0	0	0
13/05/2009	13	11	10	11	9	6	90	84	68	1017	1011	20	1	21	0	0	0
14/05/2009	18	13	11	14	11	9	90	86	78	1011	1005	15	1	16	0.1	1	0
15/05/2009	15	12	9	12	9	4	91	82	64	1005	1001	38	3	39	0.41	4.1	0
16/05/2009	16	12	9	10	8	5	92	77	59	1007	1000	42	6	42	0.2	2	0
17/05/2009	17	12	8	12	9	6	91	81	65	1008	1000	41	6	41	0.74	7.4	1
18/05/2009	17	12	9	11	9	7	90	81	64	1015	1008	36	4	36	0.46	4.6	0
19/05/2009	17	12	10	12	9	8	91	82	65	1019	1014	32	4	32	0.74	7.4	1
20/05/2009	18	13	9	13	10	7	91	81	71	1020	1016	27	3	27	0	0	0
21/05/2009	19	13	8	11	8	6	91	74	54	1017	1015	23	2	23	0.05	0.5	0
22/05/2009	22	14	6	12	9	4	90	72	52	1019	1017	20	1	21	0	0	0
23/05/2009	21	14	6	13	9	5	90	73	58	1019	1016	24	1	24	0	0	0
24/05/2009	22	16	9	14	10	8	90	73	55	1021	1019	20	2	21	0	0	0
25/05/2009	22	15	10	15	10	6	84	73	59	1020	1012	27	2	27	0	0	0
26/05/2009	18	13	10	10	7	6	88	69	50	1025	1012	39	6	39	0	0	0
27/05/2009	15	12	9	14	10	6	91	87	79	1027	1021	36	3	36	0.3	3	0
28/05/2009	20	16	12	16	13	11	92	83	71	1033	1027	18	1	19	0	0	0
29/05/2009	22	17	11	17	13	9	92	78	64	1032	1025	27	2	27	0	0	0
30/05/2009	23	18	10	12	9	7	82	59	42	1025	1024	24	2	24	0	0	0
31/05/2009	25	19	9	15	12	6	86	64	48	1026	1024	25	1	25	0	0	0
01/06/2009	26	17	16	13	13	11	77	76	75	1026	1024	23	0	24	0	0	0
02/06/2009	26	20	13	13	10	8	71	53	36	1027	1024	18	1	19	0	0	0
03/06/2009	28	20	12	17	13	8	81	66	48	1024	1019	18	1	19	0	0	0
04/06/2009	19	15	11	13	10	7	85	74	64	1021	1015	20	2	23	0	0	0
05/06/2009	22	15	8	12	8	5	89	66	45	1015	1004	23	2	23	0	0	0
06/06/2009	13	10	8	10	8	7	93	86	69	1004	998	27	1	27	4.34	43.4	1
07/06/2009	17	11	5	14	8	4	93	82	67	1005	997	31	3	32	0	0	0
08/06/2009	16	12	6	12	9	4	92	83	73	1005	1004	25	1	25	0	0	0
09/06/2009	18	13	11	11	10	8	89	79	61	1011	1004	20	2	21	0	0	0
10/06/2009	20	14	10	16	11	8	91	84	69	1012	1008	29	2	29	0	0	0
11/06/2009	22	16	9	14	10	8	92	72	54	1022	1013	26	2	26	0	0	0
12/06/2009	18	14	11	15	11	8	91	85	77	1022	1020	18	2	19	0	0	0
13/06/2009	23	17	12	18	13	10	93	79	61	1021	1018	27	2	27	0	0	0
14/06/2009	22	16	11	16	12	9	91	78	60	1020	1018	23	2	23	0	0	0
15/06/2009	22	15	11	16	12	10	91	84	63	1019	1016	20	1	21	0	0	0
16/06/2009	21	15	8	16	12	7	93	82	68	1024	1019	27	3	27	0.36	3.6	0
17/06/2009	22	15	11	16	12	9	91	84	67	1023	1014	28	2	28	0.1	1	0
18/06/2009	23	15	9	16	10	7	92	73	57	1021	1018	23	1	23	0.05	0.5	0
19/06/2009	20	15	10	13	10	8	87	71	55	1026	1020	27	3	32	0	0	0
20/06/2009	20	15	12	13	11	9	87	75	60	1027	1025	29	4	29	0	0	0
21/06/2009	22	17	12	16	12	9	91	74	59	1027	1026	25	3	25	0	0	0
22/06/2009	25	19	14	18	14	12	89	75	60	1029	1027	22	2	23	0	0	0
23/06/2009	22	18	13	17	12	7	89	72	54	1029	1025	23	1	23	0	0	0
24/06/2009	25	19	10	15	12	7	82	65	52	1025	1016	24	2	24	0	0	0
25/06/2009	24	19	13	18	13	9	82	71	63	1016	1011	17	1	17	0	0	0
26/06/2009	25	19	16	19	15	13	87	77	64	1015	1011	18	0	19	0.05	0.5	0
27/06/2009	26	19	13	19	15	12	91	75	60	1016	1015	27	2	27	0	0	0
28/06/2009	23	18	14	17	14	12	90	78	65	1016	1015	17	1	18	0	0	0
29/06/2009	25	20	15	19	15	12	87	74	64	1020	1015	27	2	27	0	0	0
30/06/2009	26	20	16	20	16	12	88	77	66	1023	1019	18	1	19	0	0	0
01/07/2009	26	17	16	15	15	13	88	88	88	1023	1020	17	0	18	0	0	0
02/07/2009	23	19	17	18	16	13	93	83	72	1022	1014	20	1	21	1.9	19	1
03/07/2009	23	19	15	19	16	13	93	84	69	1015	1013	19	1	19	0.1	1	0
04/07/2009	25	18	14	18	15	12	92	82	63	1015	1011	32	3	32	0	0	0
05/07/2009	26	18	14	18	14	12	91	77	56	1011	1008	33	3	34	0	0	0
06/07/2009	22	18	13	16	13	11	88	76	60	1008	1005	18	3	18	0.05	0.5	0
07/07/2009	20	17	13	16	14	12	93	82	69	1012	1005	40	4	40	0.94	9.4	1
08/07/2009	21	17	13	16	12	10	89	75	57	1018	1012	19	4	27	0	0	0
09/07/2009	24	16	13	14	11	8	88	71	50	1019	1017	27	3	27	0	0	0
10/07/2009	24	17	12	15	12	8	85	75	54	1019	1017	20	0	21	0.1	1	0

Date	TemperatureHighC	TemperatureAvgC	TemperatureLowC	DewpointHighC	DewpointAvgC	DewpointLowC	HumidityHigh	HumidityAvg	HumidityLow	PressureMaxhPa	PressureMinhPa	WindSpeedMaxKMH	WindSpeedAvgKMH	GustSpeedMaxKMH	PrecipitationSumCM	PPT (mm)	Events > 5mm
11/07/2009	22	17	14	18	15	12	93	87	76	1017	1006	28	4	28	0.99	9.9	1
12/07/2009	23	18	13	18	14	11	94	80	64	1010	1005	25	2	25	0.1	1	0
13/07/2009	22	16	11	17	13	9	92	84	66	1010	1006	32	3	32	0.15	1.5	0
14/07/2009	19	16	13	17	13	11	91	86	74	1008	1004	38	4	39	0.79	7.9	1
15/07/2009	22	18	14	18	14	12	92	81	67	1019	1004	32	3	32	0.89	8.9	1
16/07/2009	19	15	11	16	13	9	93	88	80	1020	1008	23	2	23	1.14	11.4	1
17/07/2009	17	14	12	14	12	10	93	88	77	1014	1004	45	6	45	0.3	3	0
18/07/2009	20	16	13	16	13	11	91	82	69	1014	1011	15	1	15	0	0	0
19/07/2009	20	16	12	15	13	10	88	81	71	1015	1011	33	3	33	0.15	1.5	0
20/07/2009	20	16	10	15	12	9	92	81	63	1016	1011	23	1	23	0.05	0.5	0
21/07/2009	18	15	14	16	14	12	93	92	90	1011	1002	32	5	32	2.06	20.6	1
22/07/2009	20	16	13	15	13	11	92	82	69	1002	1001	20	3	20	0.15	1.5	0
23/07/2009	22	16	11	16	13	9	92	81	61	1008	1001	24	2	24	0.2	2	0
24/07/2009	21	16	13	17	13	11	91	82	68	1019	1008	32	2	32	0.41	4.1	0
25/07/2009	23	17	11	16	13	9	92	78	63	1023	1019	26	1	26	0	0	0
26/07/2009	18	15	13	15	13	12	93	89	82	1022	1013	20	3	20	0.66	6.6	1
27/07/2009	20	16	12	16	12	10	93	81	62	1017	1011	27	2	27	0.3	3	0
28/07/2009	21	16	11	16	13	10	91	81	65	1017	1014	32	3	32	0.05	0.5	0
29/07/2009	16	15	12	15	13	11	93	91	84	1015	1008	18	3	23	1.6	16	1
30/07/2009	20	15	11	14	11	9	94	80	61	1024	1015	31	2	32	0.05	0.5	0
31/07/2009	20	15	12	15	12	10	91	84	68	1024	1013	24	2	24	0.36	3.6	0
01/08/2009	19	14	14	13	13	11	92	91	91	1013	1007	25	2	25	1.17	11.7	1
02/08/2009	23	16	9	16	12	8	92	79	61	1014	1011	23	1	23	0	0	0
03/08/2009	21	16	14	16	14	12	93	88	72	1014	1012	36	5	36	0.2	2	0
04/08/2009	18	17	16	17	16	15	94	93	92	1015	1012	23	4	23	0.61	6.1	1

	MAX	MEAN	MIN
E faecalis concentration (/ml)	1.84	0.92	0.09
Volume ingested (ml)	0.2	0.1	0.05
Exposure frequency (%)	0.05	0.05	0.05
Flushes/person/day	3	2	1
	Campy	Campy	Campy
alpha	-0.145	-0.145	-0.145
beta	7.589	7.589	7.589
Number of samples taken	41	0.18	0.09
Number of samples contaminated (>100 (BSI guideline))	15		
# Days (minus weekends)	261	261	261
Probability of illness (Campy)	0.3	0.3	0.3
Population	111	111	111
Severity weight	0.093	0.093	0.093
Duration	6	6	6

	MAX: Campy beta-poisson data & contamination frequency calculated from study data (0.37)	MEAN: Campylobacter beta-poisson data and contamination frequency calculated from study data (0.18)	MIN: Campylobacter beta-poisson data and contamination frequency calculated from study data (0.09)
Dose/flush	0.368	0.092	0.005
Exposure frequency	0.15	0.10	0.05
Dose/day	0.055	0.009	0.0002
Dose-Response	0.998950	0.999824	0.999996
Probability of infection/day	0.001050	0.000176	0.000004
Annual supply contamination frequency (days)	95.49	47.74	23.87
Annual probability of infection	0.100292	0.008387	0.000105
Annual cases of Illness	3.340	0.279	0.003
Annual Total DALY	1.864	0.156	0.002
Annual DALY/Person	0.017	0.001	0.000
Across a 78 yr life (UK life expectancy)	2.15E-04	1.80E-05	2.25E-07

APPENDIX E FOR CHAPTER 6

(Understanding RWH System Performance – Design and Performance Evaluation)

Contents

http://en.zenner.com/shared/files/kataloge/englisch/ZR_PK_MNK-N-L_EN_090107_Web.pdf

MNK-N-L

Multi-jet wet dial water meter

for cold potable water
retrofittable with pulser
with plastic body

ZENNER
All that counts.

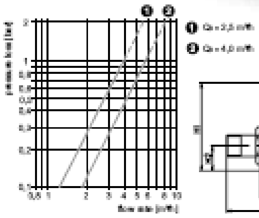
MNK-N-L

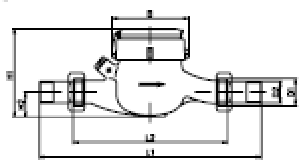
Multi-jet wet dial water meter for cold potable water

The new series of our multi-jet wet dial meter are an improvement of the classical MNK. Our developers succeeded in combining the millionfold proven and high-precise measuring insert with a body of pressure-tight plastics, suitable for use with potable water. The result is the innovative MNK-N-L.

Its main features are a low starting flow and reliable performance even with aggressive water qualities or dezincification effects. Retrofittable with pulse this meter is ready for all future AMR applications.

The construction principle of the MNK-N-L with direct transmission from the measuring chamber to the counter ensures by standard protection against magnetic or other manipulation attempts or interference.





Performance characteristics in overview

- Rugged, light and intelligently conceived
- Approx. 50% lighter than brass body
- Body made from high-grade UV-proof plastic
- Working temperature 30°C, security up to 50°C
- Operating pressure PN10
- Display range 0,05 l to 99.999 m³
- Retrofittable with pulser
- For horizontal piping
- Installation notes for plastic meters have to be followed!

Technical data					
Nominal flow*	Q3	m³/h	2,5	2,5	4
Nominal width	DN	mm	15	15	20
		inch	½	½	¾
Length without connectors	L2	mm	165	190	190
Length with connectors	L1	mm	250	288	288
Thread meter G x B	D1	inch	¾	¾	1
Metrological class*	Q3/Q1		R40 / 63 / 80 / 100		
Maximum flow*	Q4	m³/h	3,1	3,1	5
Minimum flow*	Q1	l/h	25	25	40
Start-up flow rate		l/h	4	4	5
Width	B	mm	95	95	95
Weight		gr.	560	560	580

*according to MID / OIML R49

ZENNER International GmbH & Co. KG
Römerstadt 4
D-66121 Saarbrücken
Telephone +49 681 99 676-0
Fax +49 681 99 676-100
E-Mail info@zenner.com
Internet www.zenner.com

	Rainfall (mm)	Runoff (m3)	Cumu runoff (m3)	Runoff incl Coeff (m3)	Cumu runoff incl coeff (m3)	Overflow (m3)	Overflow minus rainwater (m3)	cumu overflow (m3)		Runoff Coeff
23/12/2008	0.50	0.75	0.75	0.75	0.75			0.00	1.00	1.00
30/12/2008	0.00	0.00	0.75	0.00	0.75			0.00	1.00	1.00
06/01/2009	0	0.00	0.75	0.00	0.75			0.00	1.00	1.00
13/01/2009	1.50	2.25	3.00	2.24	2.99			0.00	1.00	1.00
20/01/2009	33.80	50.70	53.70	47.27	50.27	22.27	14.44	14.44	0.93	0.93
27/01/2009	37.90	56.85	110.55	52.54	102.81	27.54	20.44	34.88	0.92	0.92
03/02/2009	26.2	39.30	149.85	37.24	140.05	12.24	4.82	39.70	0.95	0.95
10/02/2009	47.00	70.50	220.35	63.87	203.92	38.87	31.61	71.31	0.91	0.91
17/02/2009	1.00	1.50	221.85	1.50	205.42			71.31	1.00	1.00
24/02/2009	2.50	3.75	225.60	3.73	209.15			71.31	1.00	1.00
03/03/2009	16.5	24.75	250.35	23.93	233.08			71.31	0.97	0.97
10/03/2009	25.20	37.80	288.15	35.89	268.98	10.89	2.02	73.34	0.95	0.95
17/03/2009	0.00	0.00	288.15	0.00	268.98			73.34	1.00	1.00
24/03/2009	0.00	0.00	288.15	0.00	268.98			73.34	1.00	1.00
31/03/2009	4.50	6.75	294.90	6.69	275.67			73.34	0.99	0.99
07/04/2009	5.50	8.25	303.15	8.16	283.82			73.34	0.99	0.99
14/04/2009	2.00	3.00	306.15	2.99	286.81			73.34	1.00	1.00
21/04/2009	0.00	0.00	306.15	0.00	286.81			73.34	1.00	1.00
28/04/2009	0.00	0.00	306.15	0.00	286.81			73.34	1.00	1.00
05/05/2009	11.90	17.85	324.00	17.43	304.24			73.34	0.98	0.98
12/05/2009	1.00	1.50	325.50	1.50	305.73			73.34	1.00	1.00
26/05/2009	27.00	40.50	366.00	38.31	344.05	13.31	-0.91	72.43	0.95	0.95
02/06/2009	3.00	4.50	370.50	4.47	348.52			72.43	0.99	0.99
09/06/2009	43.40	65.10	435.60	59.45	407.97	34.45	26.26	98.69	0.91	0.91
16/06/2009	3.60	5.40	441.00	5.36	413.33			98.69	0.99	0.99
23/06/2009	1.50	2.25	443.25	2.24	415.57			98.69	1.00	1.00
30/06/2009	0.50	0.75	444.00	0.75	416.32			98.69	1.00	1.00
07/07/2009	29.90	44.85	488.85	42.17	458.49	17.17	9.30	107.99	0.94	0.94
14/07/2009	21.30	31.95	520.80	30.59	489.08	5.59	-2.72	105.27	0.96	0.96
21/07/2009	17.70	26.55	547.35	25.61	514.69	0.61	-6.30	98.97	0.96	0.96
28/07/2009	39.90	59.85	607.20	55.07	569.76	30.07	22.96	121.93	0.92	0.92
04/08/2009	45.90	68.85	676.05	62.53	632.29	37.53	30.09	152.02	0.91	0.91

WHOLE BUILDING

Depression Storage (l)	Depression Storage (l)	Depression Storage (mm)	Mains Total (m3)	Mains total cumu (m3)	Rainwater Total (m3)	rainwater total cumu (m3)	Total Demand (m3)
0.00	0.75	0.00	0.50	0.50	5.62	5.62	6.12
0.00	0.00	0.00	0.00	0.50	0.88	6.50	0.88
0.00	0.00	0.00	0.00	0.50	2.16	8.66	2.16
0.01	2.24	0.00	0.50	1.00	7.93	16.59	8.43
3.43	47.22	0.03	0.50	1.50	7.83	24.42	8.33
4.31	52.48	0.03	0.00	1.50	7.10	31.52	7.10
2.06	37.20	0.02	0.00	1.50	7.42	38.94	7.42
6.63	63.80	0.04	0.50	2.00	7.26	46.21	7.76
0.00	1.50	0.00	0.50	2.50	8.43	54.63	8.93
0.02	3.73	0.00	0.00	2.50	6.78	61.41	6.78
0.82	23.91	0.02	0.00	2.50	7.54	68.95	7.54
1.91	35.86	0.02	1.00	3.50	8.87	77.82	9.87
0.00	0.00	0.00	0.00	3.50	8.89	86.71	8.89
0.00	0.00	0.00	0.00	3.50	7.48	94.19	7.48
0.06	6.68	0.00	2.50	6.00	6.06	100.25	8.56
0.09	8.15	0.01	7.50	13.50	0.00	100.25	7.50
0.01	2.99	0.00	4.50	18.00	0.00	100.25	4.50
0.00	0.00	0.00	6.50	24.50	2.77	103.02	9.27
0.00	0.00	0.00	8.00	32.50	0.00	103.02	8.00
0.42	17.41	0.01	6.00	38.50	0.00	103.02	6.00
0.00	1.50	0.00	8.50	47.00	0.03	103.05	8.53
2.19	38.27	0.03	0.50	47.50	14.22	117.27	14.72
0.03	4.47	0.00	0.00	47.50	6.84	124.11	6.84
5.65	59.38	0.04	0.50	48.00	8.19	132.30	8.69
0.04	5.36	0.00	0.00	48.00	8.25	140.55	8.25
0.01	2.24	0.00	0.50	48.50	7.44	147.99	7.94
0.00	0.75	0.00	0.50	49.00	7.44	155.43	7.94
2.68	42.12	0.03	0.50	49.50	7.87	163.30	8.37
1.36	30.56	0.02	0.00	49.50	8.31	171.61	8.31
0.94	25.58	0.02	1.00	50.50	6.91	178.52	7.91
4.78	55.01	0.04	0.00	50.50	7.11	185.63	7.11
6.32	62.46	0.04	0.00	50.50	7.44	193.07	7.44

					East Plant Room					
total demand cumu (m3)	WC demand % of runoff	ET (%)		Mains Manual (m^3)	Cumu Mains Manual (m^3)	RWH Manual (m^3)	Cumu RWH Manual (m^3)	ET (%)		Mains Manual (m^3)
6.12	12	92	4	**0**	**0**	**2.19**	**2.19**	100	4	**0.5**
7.00	0	100	4	0	0	0.3	2.49	100	4	0
9.16	0	100	4	0	0	0.91	3.4	100	4	0
17.59	27	94	4	0	0	3.22	6.62	100	4	0.5
25.92	567	94	4	0	0	2.94	9.56	100	4	0.5
33.02	740	100	4	0	0	2.35	11.91	100	4	0
40.44	502	100	4	0	0	2.82	14.73	100	4	0
48.21	823	94	4	0	0	2.32	17.05	100	4	0.5
57.13	17	94	4	0	0	2.6	19.65	100	4	0.5
63.91	55	100	4	0	0	2.35	22	100	4	0
71.45	317	100	4	0	0	2.58	24.58	100	4	0
81.32	364	90	4	0	0	2.74	27.32	100	4	1
90.21	0	100	4	0	0	2.38	29.7	100	4	0
97.69	0	100	4	0	0	2.42	32.12	100	4	0
106.25	78	71	3	0.5	0.5	1.83	33.95	79	4	2
113.75	109	0	1	2.5	3	0	33.95	0	1	5
118.25	66	0	1	1	4	0	33.95	0	1	3.5
127.52	0	30	2	2	6	0.91	34.86	31	2	4.5
135.52	0	0	1	2	8	0	34.86	0	1	6
141.52	290	0	1	1.5	9.5	0	34.86	0	1	4.5
150.05	18	0	1	3	12.5	0	34.86	0	1	5.5
164.77	260	97	4	0	12.5	4.63	39.49	100	4	0.5
171.61	65	100	4	0	12.5	2.58	42.07	100	4	0
180.30	684	94	4	0	12.5	2.68	44.75	100	4	0.5
188.55	65	100	4	0	12.5	2.65	47.4	100	4	0
196.49	28	94	4	0	12.5	2.8	50.2	100	4	0.5
204.43	9	94	4	0.5	13	2.67	52.87	84	4	0
212.80	504	94	4	0	13	2.94	55.81	100	4	0.5
221.11	368	100	4	0	13	2.46	58.27	100	4	0
229.02	324	87	4	0	13	1.88	60.15	100	4	1
236.13	775	100	4	0	13	2.4	62.55	100	4	0
243.57	840	100	4	0	13	1.5	64.05	100	4	0

West Plant room

Cumu Mains Manual (m^3)	RWH Manual (m^3)	Cumu RWH Manual (m^3)	ET (%)		Stormsaver ET%	Raincycle ET%	ET for 300 Occupancy(%)	Raincycle Mthly profile
0.5	**3.43**	**3.43**	87	4	60	46	34	73
0.5	0.58	4.01	100	4	60	46	37	73
0.5	1.25	5.26	100	4	60	46	37	72
1	4.71	9.97	90	4	60	46	35	72
1.5	4.89	14.86	91	4	60	46	35	72
1.5	4.75	19.61	100	4	60	46	37	72
1.5	4.6	24.21	100	4	60	46	37	63
2	4.945	29.155	91	4	60	46	35	63
2.5	5.825	34.98	92	4	60	46	35	63
2.5	4.43	39.41	100	4	60	46	37	63
2.5	4.96	44.37	100	4	60	46	37	49
3.5	6.13	50.5	86	4	60	46	33	49
3.5	6.51	57.01	100	4	60	46	37	49
3.5	5.06	62.07	100	4	60	46	37	49
5.5	4.23	66.3	68	3	60	46	26	49
10.5	0	66.3	0	1	60	46		42
14	0	66.3	0	1	60	46		42
18.5	1.86	68.16	29	2	60	46		42
24.5	0	68.16	0	1	60	46		42
29	0	68.16	0	1	60	46		39
34.5	0.03	68.19	1	1	60	46		39
35	9.59	77.78	95	4	60	46	36	39
35	4.26	82.04	100	4	60	46	37	33
35.5	5.51	87.55	92	4	60	46	35	33
35.5	5.6	93.15	100	4	60	46	37	33
36	4.64	97.79	90	4	60	46	35	33
36	4.77	102.56	100	4	60	46	35	33
36.5	4.93	107.49	91	4	60	46	35	32
36.5	5.85	113.34	100	4	60	46	37	32
37.5	5.03	118.37	83	4	60	46	32	32
37.5	4.71	123.08	100	4	60	46	37	32
37.5	5.94	129.02	100	4	60	46	37	39

Rainwater Harvesting System Pump Energy Consumption and Carbon Dioxide Emission Calculator

User-defined values need to be entered in the red boxes, with the exception of CO2 conversion, where a default value can be used

Input Data from Rainwater Harvesting System and Pump Specifications

Pump Rating (kW)	1.1
Pump Input Power (kW)	1.62
Pump Capacity (m^3/h)	3.39
Header Capacity (m^3)	0.8
Float Switch On Level (%)	0.75
Float Switch Off Level (%)	0.95
Start-Up Factor (%)	0.6
Start-Up Volume (m^3)	0.001
Operating-Up Volume (m^3)	0.999

Pump Capacities

Height of building	10	20	30
Power rating	Capacity (m^3/h)		
0.8	3.6	3	1.8
1	3.78	3.3	2.7
1.1	3.84	3.39	2.91
1.2	3.9	3.48	3.12
1.4	4.02	3.6	3.3

Input Monthly Rainwater Volume Pumped/Consumed (m^3)

January	1
February	2
March	3
April	4
May	5
June	6
July	7
August	8
September	9
October	10
November	11
December	12

Calculate with default CO2 conversion factor

Calculate with user-defined CO2 conversion factor

Default CO2 conversion factor: 1.043 kg/kWh

User-defined CO2 conversion factor: 2.086 kg/kWh

	Energy Consumed (kWh)	CO_2 Emission (kg)
January	0.43	0.90
February	0.87	1.82
March	1.32	2.76
April	1.78	3.72
May	2.25	4.69
June	2.72	5.68
July	3.21	6.69
August	3.70	7.72
September	4.20	8.76
October	4.71	9.83
November	5.23	10.91
December	5.76	12.01
Total	36.19	75.49
Per m3	0.46	0.97

Once data has been entered in red boxes, place cursor here, BEFORE pressing chosen button

Input Annual Rainwater Volume Pumped/Consumed (m^3): 150

Calculate with default CO2 conversion factor

Calculate with user-defined CO2 conversion factor

	Energy Consumed (kWh)	CO_2 Emission (kg)
Total	160.68	335.17
Per m^3	1.07	2.23

If unit conversions are required, use the following tool:
http://www.onlineconversion.com/

Pump Efficiency (%)	0.68

B3	YR	PS	937.50	V2	140.63	ODS	41.48	V1	149.85	ODO	44	EPOT	48.62	EPS	45.63	EPST	73.01	E2	121.63
B4	YR	PS	937.50	V2	140.63	ODS	41.48	V1	149.85	ODO	44	EPOT	48.62	EPS	45.63	EPST	73.01	E2	121.63
B2	JAN	PS	6.25	V2	0.01	ODS	0.00	V1	1.00	ODO	0	EPOT	0.32	EPS	0.00	EPST	0.00	E2	0.33
	FEB	PS	12.50	V2	0.03	ODS	0.01	V1	2.00	ODO	1	EPOT	0.65	EPS	0.01	EPST	0.01	E2	0.66
	MAR	PS	18.75	V2	0.06	ODS	0.02	V1	3.00	ODO	1	EPOT	0.97	EPS	0.02	EPST	0.03	E2	1.00
	APR	PS	25.00	V2	0.10	ODS	0.03	V1	4.00	ODO	1	EPOT	1.30	EPS	0.03	EPST	0.05	E2	1.35
	MAY	PS	31.25	V2	0.16	ODS	0.05	V1	5.00	ODO	1	EPOT	1.62	EPS	0.05	EPST	0.08	E2	1.70
	JUN	PS	37.50	V2	0.23	ODS	0.07	V1	5.99	ODO	2	EPOT	1.94	EPS	0.07	EPST	0.12	E2	2.06
	JUL	PS	43.75	V2	0.31	ODS	0.09	V1	6.99	ODO	2	EPOT	2.27	EPS	0.10	EPST	0.16	E2	2.43
	AUG	PS	50.00	V2	0.40	ODS	0.12	V1	7.99	ODO	2	EPOT	2.59	EPS	0.13	EPST	0.21	E2	2.80
	SEP	PS	56.25	V2	0.51	ODS	0.15	V1	8.99	ODO	3	EPOT	2.92	EPS	0.16	EPST	0.26	E2	3.18
	OCT	PS	62.50	V2	0.63	ODS	0.18	V1	9.99	ODO	3	EPOT	3.24	EPS	0.20	EPST	0.32	E2	3.57
	NOV	PS	68.75	V2	0.76	ODS	0.22	V1	10.99	ODO	3	EPOT	3.57	EPS	0.25	EPST	0.39	E2	3.96
	DEC	PS	75.00	V2	0.90	ODS	0.27	V1	11.99	ODO	4	EPOT	3.89	EPS	0.29	EPST	0.47	E2	4.36
B1	JAN	PS	6.25	V2	0.01	ODS	0.00	V1	1.00	ODO	0	EPOT	0.32	EPS	0.00	EPST	0.00	E2	0.33
	FEB	PS	12.50	V2	0.03	ODS	0.01	V1	2.00	ODO	1	EPOT	0.65	EPS	0.01	EPST	0.01	E2	0.66
	MAR	PS	18.75	V2	0.06	ODS	0.02	V1	3.00	ODO	1	EPOT	0.97	EPS	0.02	EPST	0.03	E2	1.00
	APR	PS	25.00	V2	0.10	ODS	0.03	V1	4.00	ODO	1	EPOT	1.30	EPS	0.03	EPST	0.05	E2	1.35
	MAY	PS	31.25	V2	0.16	ODS	0.05	V1	5.00	ODO	1	EPOT	1.62	EPS	0.05	EPST	0.08	E2	1.70
	JUN	PS	37.50	V2	0.23	ODS	0.07	V1	5.99	ODO	2	EPOT	1.94	EPS	0.07	EPST	0.12	E2	2.06
	JUL	PS	43.75	V2	0.31	ODS	0.09	V1	6.99	ODO	2	EPOT	2.27	EPS	0.10	EPST	0.16	E2	2.43
	AUG	PS	50.00	V2	0.40	ODS	0.12	V1	7.99	ODO	2	EPOT	2.59	EPS	0.13	EPST	0.21	E2	2.80
	SEP	PS	56.25	V2	0.51	ODS	0.15	V1	8.99	ODO	3	EPOT	2.92	EPS	0.16	EPST	0.26	E2	3.18
	OCT	PS	62.50	V2	0.63	ODS	0.18	V1	9.99	ODO	3	EPOT	3.24	EPS	0.20	EPST	0.32	E2	3.57
	NOV	PS	68.75	V2	0.76	ODS	0.22	V1	10.99	ODO	3	EPOT	3.57	EPS	0.25	EPST	0.39	E2	3.96
	DEC	PS	75.00	V2	0.90	ODS	0.27	V1	11.99	ODO	4	EPOT	3.89	EPS	0.29	EPST	0.47	E2	4.36

```
Private Sub CommandButton1_Click()
'PumpECTool Macro
' Macro recorded 26/03/2010 by Sarah Ward

 ActiveCell.FormulaR1C1 = "=R[-37]C[-7]/R[-36]C[-7]"
    Range("E64").Select
    ActiveCell.FormulaR1C1 = _
        "=R[-41]C/((R[-52]C[2]*R[-50]C[2])-(R[-52]C[2]*R[-51]C[2]))"
    Range("H64").Select
    ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-48]C[-1]"
    Range("K64").Select
    ActiveCell.FormulaR1C1 = "=RC[-3]/R[-53]C[-4]"
    Range("M64").Select
    ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-47]C[-6]"
    Range("O64").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]/R[-53]C[-8]"
    Range("G9").Select
    Range("Q64").Select
    ActiveCell.FormulaR1C1 = "=R[-55]C[-10]*RC[-2]"
    Range("S64").Select
    ActiveCell.FormulaR1C1 = "=R[-55]C[-12]*RC[-8]"
    Range("U64").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-49]C[-14])"
    Range("W64").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
    Range("M22").Select
    ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[24]C[1]))"
    Range("N22").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]*R[9]C[-6]"
    Range("E65").Select
    ActiveCell.FormulaR1C1 = _
        "=R[-41]C/((R[-53]C[2]*R[-51]C[2])-(R[-53]C[2]*R[-52]C[2]))"
    Range("H65").Select
    ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-49]C[-1]"
    Range("K65").Select
    ActiveCell.FormulaR1C1 = "=RC[-3]/R[-54]C[-4]"
    Range("M65").Select
    ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-48]C[-6]"
    Range("O65").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]/R[-54]C[-8]"
    Range("Q65").Select
    ActiveCell.FormulaR1C1 = "=R[-56]C[-10]*RC[-2]"
    Range("S65").Select
    ActiveCell.FormulaR1C1 = "=R[-56]C[-12]*RC[-8]"
    Range("U65").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-50]C[-14])"
    Range("W65").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
    Range("M23").Select
    ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[23]C[1]))"
    Range("N23").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]*R[8]C[-6]"
```

```
Range("E66").Select
ActiveCell.FormulaR1C1 = _
   "=R[-41]C/((R[-54]C[2]*R[-52]C[2])-(R[-54]C[2]*R[-53]C[2]))"
Range("H66").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-50]C[-1]"
Range("K66").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-55]C[-4]"
Range("M66").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-49]C[-6]"
Range("O66").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-55]C[-8]"
Range("Q66").Select
ActiveCell.FormulaR1C1 = "=R[-57]C[-10]*RC[-2]"
Range("S66").Select
ActiveCell.FormulaR1C1 = "=R[-57]C[-12]*RC[-8]"
Range("U66").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-51]C[-14])"
Range("W66").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
Range("M24").Select
ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[22]C[1]))"
Range("N24").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[7]C[-6]"
Range("E67").Select
ActiveCell.FormulaR1C1 = _
   "=R[-41]C/((R[-55]C[2]*R[-53]C[2])-(R[-55]C[2]*R[-54]C[2]))"
Range("H67").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-51]C[-1]"
Range("K67").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-56]C[-4]"
Range("M67").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-50]C[-6]"
Range("O67").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-56]C[-8]"
Range("Q67").Select
ActiveCell.FormulaR1C1 = "=R[-58]C[-10]*RC[-2]"
Range("S67").Select
ActiveCell.FormulaR1C1 = "=R[-58]C[-12]*RC[-8]"
Range("U67").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-52]C[-14])"
Range("W67").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
Range("M25").Select
ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[21]C[1]))"
Range("N25").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[6]C[-6]"
Range("E68").Select
ActiveCell.FormulaR1C1 = _
   "=R[-41]C/((R[-56]C[2]*R[-54]C[2])-(R[-56]C[2]*R[-55]C[2]))"
Range("H68").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-52]C[-1]"
Range("K68").Select
```

```
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-57]C[-4]"
Range("M68").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-51]C[-6]"
Range("O68").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-57]C[-8]"
Range("Q68").Select
ActiveCell.FormulaR1C1 = "=R[-59]C[-10]/RC[-2]"
Range("Q68").Select
ActiveCell.FormulaR1C1 = "=R[-59]C[-10]*RC[-2]"
Range("S68").Select
ActiveCell.FormulaR1C1 = "=R[-59]C[-12]*RC[-8]"
Range("U68").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-53]C[-14])"
Range("W68").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
Range("M26").Select
ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[20]C[1]))"
Range("N26").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[5]C[-6]"
Range("E69").Select
ActiveCell.FormulaR1C1 = _
   "=R[-41]C/((R[-57]C[2]*R[-55]C[2])-(R[-57]C[2]*R[-56]C[2]))"
Range("H69").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-53]C[-1]"
Range("K69").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-58]C[-4]"
Range("M69").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-52]C[-6]"
Range("O69").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-58]C[-8]"
Range("Q69").Select
ActiveCell.FormulaR1C1 = "=R[-60]C[-10]*RC[-2]"
Range("S69").Select
ActiveCell.FormulaR1C1 = "=R[-60]C[-12]*RC[-8]"
Range("U69").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-54]C[-14])"
Range("W69").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
Range("M27").Select
ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[19]C[1]))"
Range("N27").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[4]C[-6]"
Range("E70").Select
ActiveCell.FormulaR1C1 = _
   "=R[-41]C/((R[-58]C[2]*R[-56]C[2])-(R[-58]C[2]*R[-57]C[2]))"
Range("H70").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-54]C[-1]"
Range("K70").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-59]C[-4]"
Range("M70").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-53]C[-6]"
Range("O70").Select
```

```
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-59]C[-8]"
Range("Q70").Select
ActiveCell.FormulaR1C1 = "=R[-61]C[-10]*RC[-2]"
Range("S70").Select
ActiveCell.FormulaR1C1 = "=R[-61]C[-12]*RC[-8]"
Range("U70").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-55]C[-14])"
Range("W70").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
Range("M28").Select
ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[18]C[1]))"
Range("N28").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[3]C[-6]"
Range("E71").Select
ActiveCell.FormulaR1C1 = _
  "=R[-41]C/((R[-59]C[2]*R[-57]C[2])-(R[-59]C[2]*R[-58]C[2]))"
Range("H71").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-55]C[-1]"
Range("K71").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-60]C[-4]"
Range("M71").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-54]C[-6]"
Range("O71").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-60]C[-8]"
Range("Q71").Select
ActiveCell.FormulaR1C1 = "=R[-62]C[-10]*RC[-2]"
Range("S71").Select
ActiveCell.FormulaR1C1 = "=R[-62]C[-12]*RC[-8]"
Range("U71").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-56]C[-14])"
Range("W71").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
Range("M29").Select
ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[17]C[1]))"
Range("N29").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[2]C[-6]"
Range("E72").Select
ActiveCell.FormulaR1C1 = _
  "=R[-41]C/((R[-60]C[2]*R[-58]C[2])-(R[-60]C[2]*R[-59]C[2]))"
Range("H72").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-56]C[-1]"
Range("K72").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-61]C[-4]"
Range("M72").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-55]C[-6]"
Range("O72").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-61]C[-8]"
Range("Q72").Select
ActiveCell.FormulaR1C1 = "=R[-63]C[-10]*RC[-2]"
Range("S72").Select
ActiveCell.FormulaR1C1 = "=R[-63]C[-12]*RC[-8]"
Range("U72").Select
```

```
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-57]C[-14])"
Range("W72").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
Range("M30").Select
ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[16]C[1]))"
Range("N30").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[1]C[-6]"
Range("E73").Select
ActiveCell.FormulaR1C1 = _
   "=R[-41]C/((R[-61]C[2]*R[-59]C[2])-(R[-61]C[2]*R[-60]C[2]))"
Range("H73").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-57]C[-1]"
Range("K73").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-62]C[-4]"
Range("M73").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-56]C[-6]"
Range("O73").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-62]C[-8]"
Range("Q73").Select
ActiveCell.FormulaR1C1 = "=R[-64]C[-10]*RC[-2]"
Range("S73").Select
ActiveCell.FormulaR1C1 = "=R[-64]C[-12]*RC[-8]"
Range("U73").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-58]C[-14])"
Range("W73").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
Range("M31").Select
ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[15]C[1]))"
Range("N31").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*RC[-6]"
Range("E74").Select
ActiveCell.FormulaR1C1 = _
   "=R[-41]C/((R[-62]C[2]*R[-60]C[2])-(R[-62]C[2]*R[-61]C[2]))"
Range("H74").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-58]C[-1]"
Range("K74").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-63]C[-4]"
Range("M74").Select
ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-57]C[-6]"
Range("O74").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-63]C[-8]"
Range("Q74").Select
ActiveCell.FormulaR1C1 = "=R[-65]C[-10]*RC[-2]"
Range("S74").Select
ActiveCell.FormulaR1C1 = "=R[-65]C[-12]*RC[-8]"
Range("U74").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-59]C[-14])"
Range("W74").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
Range("M32").Select
ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[14]C[1]))"
Range("N32").Select
```

```
    ActiveCell.FormulaR1C1 = "=RC[-1]*R[-1]C[-6]"
    Range("E75").Select
    ActiveCell.FormulaR1C1 = _
        "=R[-41]C/((R[-63]C[2]*R[-61]C[2])-(R[-63]C[2]*R[-62]C[2]))"
    Range("H75").Select
    ActiveCell.FormulaR1C1 = "=R[-41]C[-3]*RC[-3]*R[-59]C[-1]"
    Range("K75").Select
    ActiveCell.FormulaR1C1 = "=RC[-3]/R[-64]C[-4]"
    Range("M75").Select
    ActiveCell.FormulaR1C1 = "=R[-41]C[-8]*R[-58]C[-6]"
    Range("O75").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]/R[-64]C[-8]"
    Range("Q75").Select
    ActiveCell.FormulaR1C1 = "=R[-66]C[-10]*RC[-2]"
    Range("S75").Select
    ActiveCell.FormulaR1C1 = "=R[-66]C[-12]*RC[-8]"
    Range("U75").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-60]C[-14])"
    Range("W75").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
    Range("M33").Select
    ActiveCell.FormulaR1C1 = "=R[42]C[10]+(R[42]C[10]*(1-R[13]C[1]))"
    Range("N33").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]*R[-2]C[-6]"
    Range("M34").Select
    ActiveCell.FormulaR1C1 = "=SUM(R[-12]C:R[-1]C)/(SUM(R[-11]C[-8]:RC[-8]))"
    Range("N34").Select
    ActiveCell.FormulaR1C1 = "=SUM(R[-12]C:R[-1]C)/SUM(R[-11]C[-9]:RC[-9])"
    Range("M34").Select
    ActiveCell.FormulaR1C1 = "=SUM(R[-12]C:R[-1]C)"
    Range("N34").Select
    ActiveCell.FormulaR1C1 = "=SUM(R[-12]C:R[-1]C)"
    Range("M35").Select
    ActiveCell.FormulaR1C1 = "=R[-1]C/SUM(R[-12]C[-8]:R[-1]C[-8])"
    Range("N35").Select
    ActiveCell.FormulaR1C1 = "=R[-1]C/SUM(R[-12]C[-9]:R[-1]C[-9])"
    Range("N46").Select

End Sub

Private Sub CommandButton2_Click()

ActiveCell.FormulaR1C1 = "=R[-37]C[-7]/R[-36]C[-7]"
    ActiveCell.Offset(5, -9).Range("A1").Select
    ActiveCell.FormulaR1C1 = _
        "=R[-28]C/((R[-39]C[2]*R[-37]C[2])-(R[-39]C[2]*R[-38]C[2]))"
    ActiveCell.Offset(0, 3).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-35]C[-1]"
    ActiveCell.Offset(0, 3).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-3]/R[-40]C[-4]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-34]C[-6]"
```

```
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-40]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-42]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-42]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-36]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[24]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[13]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-40]C[2]*R[-38]C[2])-(R[-40]C[2]*R[-39]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-36]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-41]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-35]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-41]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-43]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-43]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-37]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[23]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[12]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-41]C[2]*R[-39]C[2])-(R[-41]C[2]*R[-40]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-37]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-42]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-36]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-42]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-44]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-44]C[-12]*RC[-8]"
```

```
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-38]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[22]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[11]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-42]C[2]*R[-40]C[2])-(R[-42]C[2]*R[-41]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-38]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-43]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-37]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-43]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-45]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-45]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-39]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[21]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[10]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-43]C[2]*R[-41]C[2])-(R[-43]C[2]*R[-42]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-39]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-44]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-38]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-44]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-46]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-46]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-40]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[20]C[1]))"
```

```
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[9]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-44]C[2]*R[-42]C[2])-(R[-44]C[2]*R[-43]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-40]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-45]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-39]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-45]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-47]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-47]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-41]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[19]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[8]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-45]C[2]*R[-43]C[2])-(R[-45]C[2]*R[-44]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-41]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-46]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-40]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-46]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-48]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-48]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-42]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[18]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[7]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-46]C[2]*R[-44]C[2])-(R[-46]C[2]*R[-45]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
```

```
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-42]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-47]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-41]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-47]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-49]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-49]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-43]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[17]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[6]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-47]C[2]*R[-45]C[2])-(R[-47]C[2]*R[-46]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-43]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-48]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-42]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-48]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-50]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-50]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-44]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[16]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[5]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-48]C[2]*R[-46]C[2])-(R[-48]C[2]*R[-47]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-44]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-49]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-43]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
```

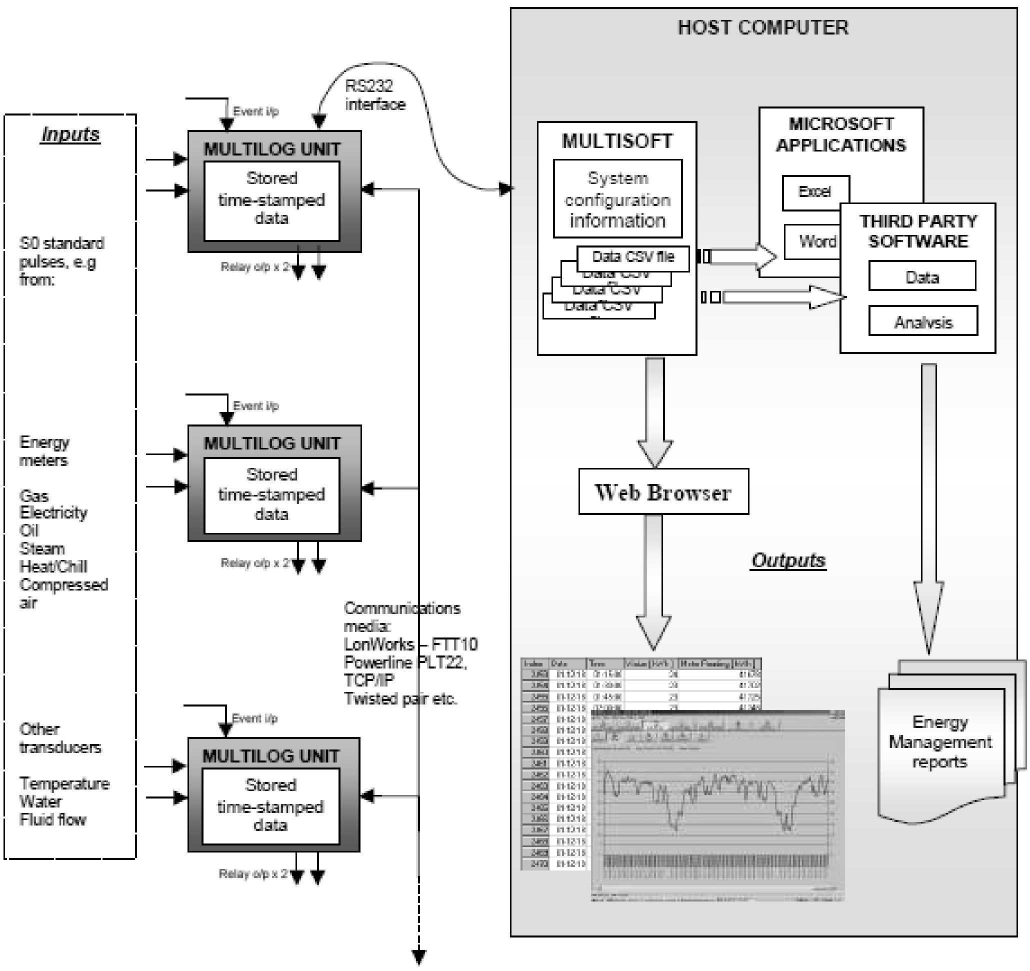
```
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-49]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-51]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-51]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-45]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[15]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[4]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-49]C[2]*R[-47]C[2])-(R[-49]C[2]*R[-48]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-45]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-50]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-44]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-50]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-52]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-52]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-46]C[-14])"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
ActiveCell.Offset(-29, -10).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[14]C[1]))"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]*R[3]C[-6]"
ActiveCell.Offset(30, -9).Range("A1").Select
ActiveCell.FormulaR1C1 = _
   "=R[-28]C/((R[-50]C[2]*R[-48]C[2])-(R[-50]C[2]*R[-49]C[2]))"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-3]*RC[-3]*R[-46]C[-1]"
ActiveCell.Offset(0, 3).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-3]/R[-51]C[-4]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-28]C[-8]*R[-45]C[-6]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-2]/R[-51]C[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-53]C[-10]*RC[-2]"
ActiveCell.Offset(0, 2).Range("A1").Select
ActiveCell.FormulaR1C1 = "=R[-53]C[-12]*RC[-8]"
ActiveCell.Offset(0, 2).Range("A1").Select
```

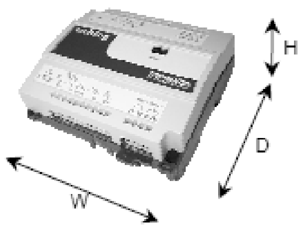
```
    ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-47]C[-14])"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
    ActiveCell.Offset(-29, -10).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[29]C[10]+(R[29]C[10]*(1-R[13]C[1]))"
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]*R[2]C[-6]"
    ActiveCell.Offset(1, -1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=SUM(R[-12]C:R[-1]C)"
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=SUM(R[-12]C:R[-1]C)"
    ActiveCell.Offset(1, -1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-1]C/(SUM(R[-12]C[-8]:R[-1]C[-8]))"
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-1]C/(SUM(R[-12]C[-9]:R[-1]C[-9]))"
    ActiveCell.Offset(11, 0).Range("A1").Select

End Sub

Private Sub CommandButton3_Click()
ActiveCell.FormulaR1C1 = "=R[-37]C[-7]/R[-36]C[-7]"
    ActiveCell.Offset(2, -9).Range("A1").Select
    ActiveCell.FormulaR1C1 = _
        "=R[-9]C[1]/((R[-36]C[2]*R[-34]C[2])-(R[-36]C[2]*R[-35]C[2]))"
    ActiveCell.Offset(0, 3).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-9]C[-2]*RC[-3]*R[-32]C[-1]"
    ActiveCell.Offset(0, 3).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-3]/R[-37]C[-4]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-9]C[-7]*R[-31]C[-6]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]/R[-37]C[-8]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-39]C[-10]*RC[-2]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-39]C[-12]*RC[-8]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-33]C[-14])"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
    ActiveCell.Offset(-7, -10).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[7]C[10]+(R[7]C[10]*(1-R[5]C[1]))"
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]*R[-10]C[-6]"
    ActiveCell.Offset(1, -1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-1]C/R[-3]C[-7]"
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-1]C/R[-3]C[-8]"
    ActiveCell.Offset(4, 0).Range("A1").Select
End Sub
```

```
Private Sub CommandButton4_Click()

ActiveCell.FormulaR1C1 = "=R[-37]C[-7]/R[-36]C[-7]"
    ActiveCell.Offset(3, -9).Range("A1").Select
    ActiveCell.FormulaR1C1 = _
        "=R[-10]C[1]/((R[-37]C[2]*R[-35]C[2])-(R[-37]C[2]*R[-36]C[2]))"
    ActiveCell.Offset(0, 3).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-10]C[-2]*RC[-3]*R[-33]C[-1]"
    ActiveCell.Offset(0, 3).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-3]/R[-38]C[-4]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-10]C[-7]*R[-32]C[-6]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]/R[-38]C[-8]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-40]C[-10]*RC[-2]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-40]C[-12]*RC[-8]"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+(RC[-2]*R[-34]C[-14])"
    ActiveCell.Offset(0, 2).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-2]+RC[-6]"
    ActiveCell.Offset(-8, -10).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[8]C[10]+(R[8]C[10]*(1-R[5]C[1]))"
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]*R[-6]C[-6]"
    ActiveCell.Offset(1, -1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-1]C/R[-3]C[-7]"
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.FormulaR1C1 = "=R[-1]C/R[-3]C[-8]"
    ActiveCell.Offset(4, 0).Range("A1").Select

End Sub
```

enercom

Multilog System architecture:





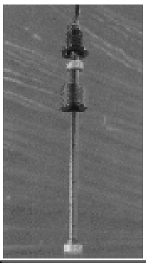
Multilog unit

Dimensions:	W = 125 mm
	D = 117 mm
	H = 52 mm
Mounting:	DIN rail

Crydom Magnetics Ltd

CRYDOM
Control over power

Model RSF66 Dual Position Series



- WBS approved
- Simple to mount and use
- PPS material
- Extension Tubes available
- Many variants are UL recognised components File Number E171218

The RSF66 floatswitch series has been specifically designed to offer the user a deep penetration float with a number of switching options to cater for a variety of system requirements. Manufactured from high grade Polyphenylene Sulphide (PPS) the RSF66 is compatible with most liquids and chemicals offering switching capabilities up to 24OV AC.

TECHNICAL SPECIFICATIONS	RSF66	ELECTRICAL SPECIFICATIONS	
Material	PPS	VA Rating	25
Colour	Grey	Breakdown Voltage DC	800
Temp. Range °C	-10 / 85	Switching Voltage AC	240
°F	+14 / 185	Switching Voltage DC	120
Min. Fluid S.G.	0.85	Switching Current Max. A	0.6

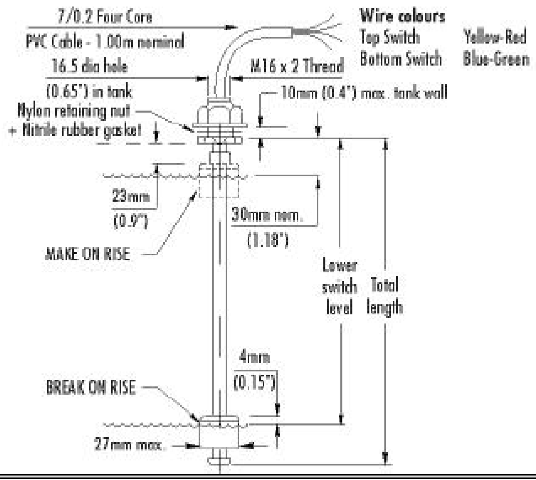
Crydom no.	Upper Switch Level	Lower Switch Level	Total Length	Gasket
RSF66A25B75	25mm	75mm	102mm	Nitrile
RSF66A25B100	25mm	100mm	127mm	Nitrile
RSF66A25B125	25mm	125mm	152mm	Nitrile
RSF66A25B150	25mm	150mm	177mm	Nitrile
RSF66A25B175	25mm	175mm	202mm	Nitrile

Notes on Part Number
Upper switch is open when level is low, closing when level rises to 25mm from top.
Lower switch is open when level is high, closing when level falls to the lower switch level.

Chemical Compatibility

Installation Instructions

OUTLINE DIMENSIONS



FALCON

HED261

018359-01 Issue 1 11/99

Specification

Display
8 digit, 8mm high contrast LCD characters

Current consumption
Counting 6µA, standby 3µA, backlight 80mA max

Operating Temperature
0°C to +50°C

Storage Temperature
-20°C to +70°C

Supply voltage (pin 1)
2.7 – 3.3VDC

Low Speed Count Input (pin 2)
Contact closure/open collector input, 30Hz max, negative edge triggered, 0.7V threshold 18V max, 15mS min. pulse length

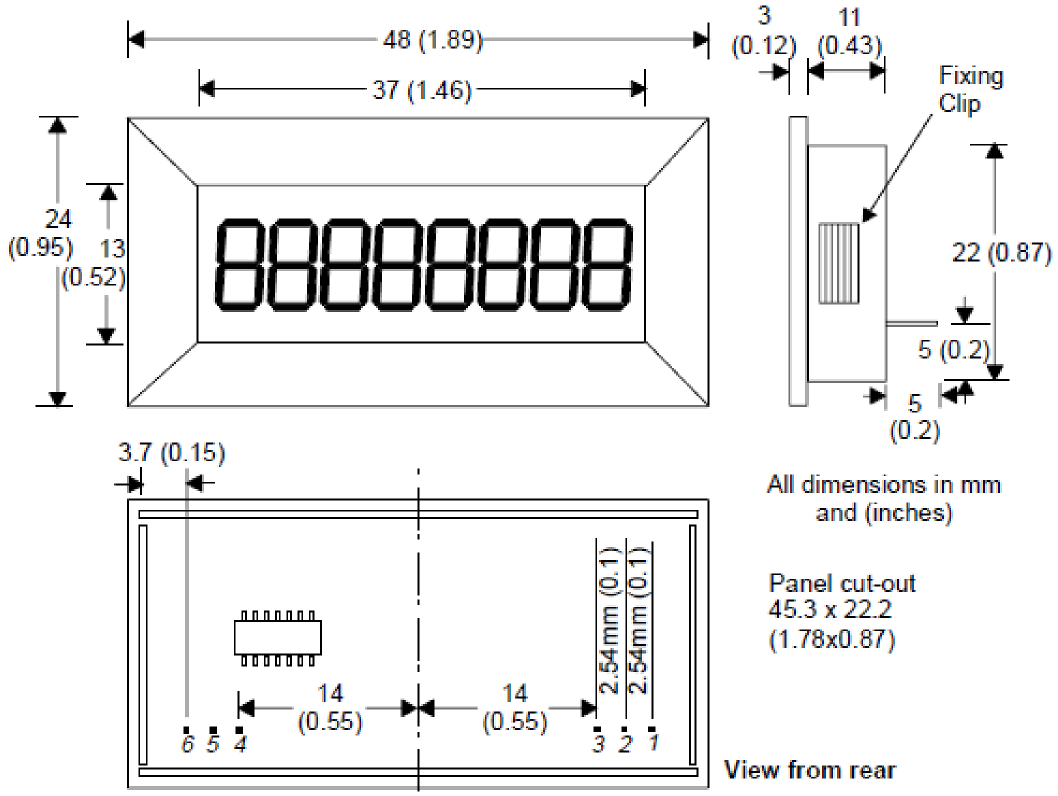
Electronic Count Input (pin 3)
10kHz max, positive edge triggered, 0.7V threshold, 18V max, 50µS min. pulse length, TTL/CMOS compatible.

Reset Input (pin 4)
Contact closure/open collector, negative edge triggered, 0.7V threshold 18V max, 15mS min. pulse length

Common (pin 5)
Supply 0V and signal common.

Backlight (pin 6)
Connect to 5V ±0.5V

Dimensions



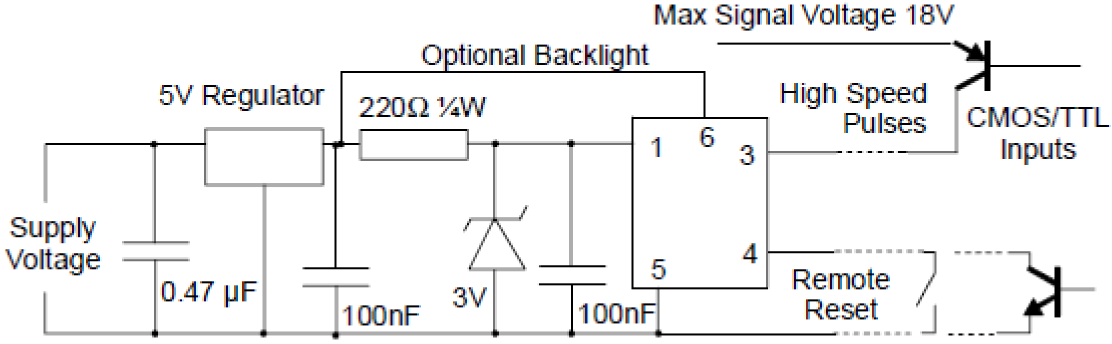
This counter is in two variants, HED261-R with reflective display and HED261-T with LED backlight. Connection is via 2 sets of 3 pins at 0.1 inch pitch, spaced as shown.

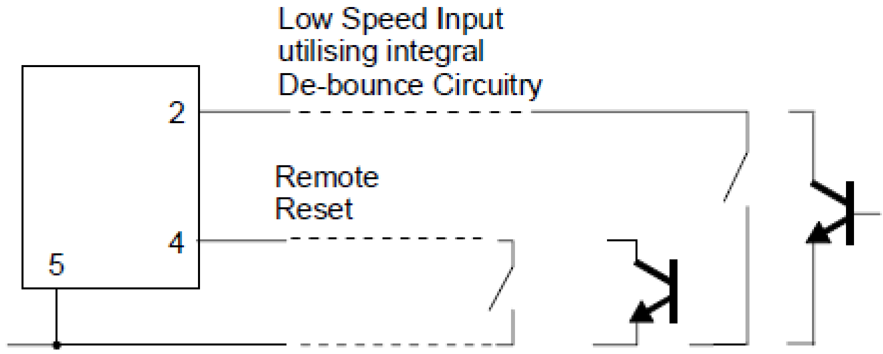
The unit is fixed to the panel using the two spring clips which are integral to the housing. The unit is the correct way up when the pins are at the bottom.

It can be powered from a higher DC voltage using the external circuit shown. For a 5v supply omit the regulator. Use the regulator for a supply in the range 8 - 30v. The regulator accommodates the different current requirements for the reflective and backlight models.

Note:

This product is ideally suited to battery powered applications. Should the product be used in a circuit where an external power source is used, then the complete system will require separate approval to meet the CE standards.





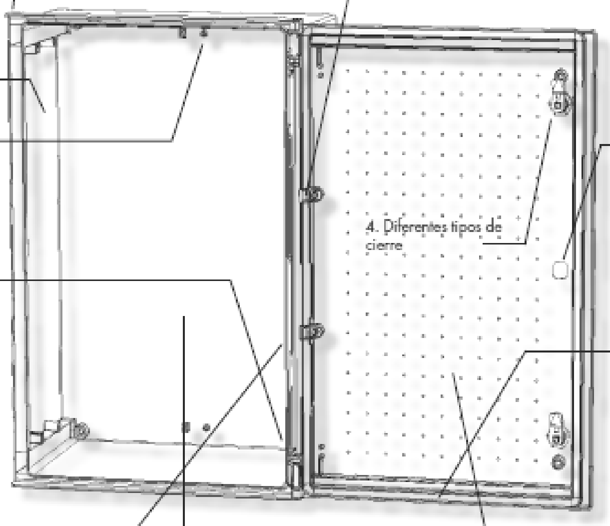
Mount the 100nF (transient suppression) capacitor as close to the unit as possible.

The low speed input (pin 2) should always be used for contact closure because this is the only input which contains de-bounce circuitry.

http://www.safybox.com/web/catalogo/envolventes/electricidadeng/BRES.htm

Uriarte Safybox

armario de polyester



1. Envolvente de doble aislamiento con agujeros para fijación directa a pared que dejan el interior del armario totalmente aislado.
   Sistemas de fijación para doble aislamiento:
   A) Fijación directa usando los agujeros de doble aislamiento.
   B) Fijación indirecta con orejeta de fijación con diferentes ángulos.
2. Sistema patentado que evita el arqueo de la puerta y mejora el sistema de tercera bisagra y facilita el montaje y desmontaje de la puerta.
3. Posibilidad de instalar nuestro cierre patentado con posibilidad de candado Safybox APM.
4. Existen muchos tipos de cierre a su disposición, triple cierre con accionamiento individual, triple cierre con maneta y un solo accionamiento,...
5. Posibilidad de instalar puerta interna.
6. El armario es simétrico, por lo que permite la apertura de la puerta de derecha a izquierda o viceversa, tan solo dando la vuelta al armario
7. La puerta dispone de unas pequeñas guías en su cara interna para facilitar el taladro y la instalación de instrumentación.
8. La distancia entre los agujeros de fijación a pared está marcada en la parte trasera del cuerpo del armario par facilitar su instalación.

Nota: Todos los armarios Safybox Bres, se suministrarán con la puerta desmontada y los ejes pasantes de la bisagra pegados en la puerta. Así se facilita el trabajo previo en el interior del armario y además es más fácil fijarlo a la pared utilizando los agujeros de doble aislamiento. De esta manera el instalador comprobará la facilidad de quitar y poner la puerta con nuestro patentado sistema de bisagras.

NOTA : Uriarte Safybox recomienda usar los agujeros de doble aislamiento para garantizar el grado de estanqueidad y en definitiva la durabilidad del equipo instalado en la envolvente.
El uso de orejetas de fijación queda a la elección del instalador ya que el Safybox-BRES ha sido especialmente diseñado para ser montado a la pared sin ellas.

Table E-1

Reference (R)	System Type	Method Used	Boundary (e.g. pumping/treatment)	Energy Consumption	Energy Consumption kWh/m^3	CO2 Emission	CO2 Emission $kgCO_2e/m^3$ equivalent
RWH System							
This study (TS)	Office building (1.1 kW pump)	Improved Method	Pumping only	0.54 kWh/m3	**0.54**	0.56 $kgCO_2e/m^3$	0.56
EA (2010)	Various	Assumption	Pumping only (direct feed; header tank)	1.5; 1.0 kWh/m^3	**1 – 1.5**	0.89; 0.59 $kgCO_2e/ML$	0.00089 – 0.00059
(A)	Various (household, hotel, office, school)	AICC/AISC	Pumping only (direct feed; header tank)	Not calculated		4 – 897 $kgCO_2e$/7-1521m^3	0.57 – 0.59
Retamal et al (2009)a (B)	Household	Comparison of theoretical pump model with monitored data	Pumping only (for WC)	Model (0.75 kW pump) = 2.7 kWh/m^3 Monitored (3 pumps, 0.5-0.89 kW) = 1.7 – 2.4 kWh/m^3	**1.7 – 2.7**		
Retamal et al (2009)b (C)	Various	NA	Unknown	1.0 – 1.7 kWh/kL	**1 – 1.7**		
EA (2008) GHG report (D)	Community and household	AICC/AISC (Electricity-Carbon Conversion Factor = 0.43 $kgCO_2e/kWh$ (defined by DEFRA))	Pumping, treatment and embedded			2400 – 4800 tCO_2eq/40Ml	0.06
EA (2009) Water Resource Strategy (E)	Household retrofit	NA	Unknown			2.67 $kgCO_2e$/day/house	7.42 (assuming daily PCC of 150l and occupancy of 2.4)
	Community retrofit	NA	Unknown			2.56 $kgCO_2e$/day/house	7.11 (assuming daily PCC of 150l and occupancy of 2.4)
Gardner *et al.* (2008) (F)	Household and communal (0.45-0.75 kW pump; 22kW pump)	NA	Pumping (specific energy use)	540 – 2600 kWh/Ml; 3.5 kWh/day	**0.54 – 2.6**	3.5 $kgCO_2e$/day	
			UV additional	1960 kWh/Ml	**0.19**		
Nolde (2007) (G)	Development-scale with non-standard catchments (e.g. courtyards, low-polluted streets)	Not confirmed	Treatment (28 W UV) and distribution	0.88 kWh/m^3	**0.88**		
Gardner et al (2006) (H)	Individual households, with pumped central overflow facility	NA		2.6 kWh/kL	**2.6**		
BSRIA (2001)	Office building	Monitored pump/UV data	Pumping (UV)	7.1 kWh/m^3 (2.97 $kWh.m^3$)	**7.1**		
(I)	Office building	Monitored pump data	Pumping only	1.94 kWh/m^3	**1.94**		
	Household	Monitored pump/UV data	Pumping (UV)	1.79 kWh/m^3 (8.76 kWh/m^3)	**1.79**		
Crettaz *et al.* (1999) (J)	Household	Reference value	Pumping only	0.09 kWh/m^3	**0.09**		
Bronchi (1999) (K)	Household						

Table E-1 (Continued)

Reference (R)	System Type	Method Used	Boundary (e.g. pumping/treatment)	Energy Consumption	Energy Consumption kWh/m^3	CO2 Emission	CO2 Emission $kgCO_2e/m^3$ equivalent
Centralised Water Distribution System (WDS)							
EA (2010) (A)	Mains water delivered, UK WSPs	NA	Source, abstraction, conveyance, treatment, distribution			382.3 $kgCO_2e/ML$	0.38
	Sewage pumping	NA	Wastewater treatment			98 $kgCO_2e/ML$	0.098
Retamal et al (2009)b (C)	Surface water treatment, California	NA		0.55 kWh/kL	**0.55**		
	WDS delivery, California	NA		0.21 kWh/kL (ave), (max 1.16kWh/kL)	**0.21 (1.16 max)**		
	Wastewater treatment, California	NA		0.28 – 1.1 kWh/kL	**0.28 – 1.1**		
	Water supplied, Southern California (high number of inter-catchment transfers)	NA		1.6 – 2.43 kWh/kL	**1.6 – 2.43**		
	Water supplied, Sydney (increasing number of inter-catchment transfers)	NA		1.03 kWh/kL (increased from 0.25 in last 7 yrs)	**1.03**		
Retamal et al (2009)b (C)	Water Supplied, Adelaide (increased pumping due to drought)	NA		1.84 kWh/kL (increased from 0.85)	**1.84**		
	Water supplied, Perth (desalination plant construction)	NA		0.98 kWh.kL (increased from 0.56)	**0.98**		
Gardner *et al.* (2008) (F)	Reticulated potable water distribution, Brisbane	NA		60 kWh/Ml	**0.06**		
	Reticulated potable water distribution, Gold Coast	NA		220 kWh/Ml	**0.22**		
Crettaz *et al.* (1999) (J)	Electricity supply for water supply, Switzerland	Reference value	Supply, wastewater	0.35 kWh/m^3	**0.35**		