

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



Submitted by

Sarah Louise Ward

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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.*

CONTENTS

Abstract.....	2
List of Figures.....	11
List of Tables.....	17
List of Tables.....	17
List of Abbreviations and Notations.....	20
Acknowledgments.....	25
1 Chapter 1: Introduction.....	26
1.1 Background.....	26
1.2 Research Perspective.....	27
1.3 Aim, Objectives and Research Questions.....	31
1.4 Research Approach.....	34
1.5 Originality and Contribution.....	36
1.6 Thesis Structure.....	38
2 Chapter 2: Literature Review.....	40
2.1 Sustainable Development, SWM and IWM.....	41
2.2 SWM in the UK.....	44
2.2.1 Increased Water Demand.....	47
2.2.2 Increased Flood Occurrence.....	53
2.2.2.1 SUDS.....	55
2.3 RWH as a SWM Technique.....	56
2.3.1 RWH for Demand Management.....	57
2.3.2 RWH for Stormwater Management (SM).....	60
2.3.3 RWH for Demand <i>and</i> Stormwater Management.....	64
2.3.4 RWH System Types.....	66
2.3.5 Conventional RWH System Components.....	69
2.3.5.1 Energy Consumption.....	71
2.3.6 Innovative and Experimental RWH Systems.....	71
2.3.7 RWH System Tank Sizing.....	74
2.3.8 RWH System Sizing Tools.....	76
2.3.9 RWH System Water Quality.....	79
2.3.9.1 Microbiological Parameters.....	84
2.3.9.2 Physico-chemical Parameters and Heavy Metals.....	85
2.3.9.3 RWH Water Quality Guidelines and Standards.....	86

2.3.10	Barriers to RWH Implementation	90
2.3.11	Contrasting the UK RWH Situation to Other Countries.....	94
2.3.11.1	Japan.....	94
2.3.11.2	Germany.....	97
2.3.11.3	Australia	99
2.3.11.4	UK Comparison	102
2.4	SWM, RWH and Social Research	105
2.4.1	RWH and Applied Social Research	106
2.4.2	RWH and Theoretical Social Research.....	110
2.4.2.1	Technology Diffusion	110
2.4.2.2	Transition Theory.....	112
2.4.2.3	Model of Receptivity.....	115
2.4.2.4	Self-efficacy, Social Identification and Social Representations	117
2.5	Chapter Summary and Implications.....	119
2.5.1	Summary	119
2.5.2	Implications for the Research Design	122
2.5.3	Justification of Stakeholder Group Selection.....	123
2.5.3.1	SMEs.....	123
2.5.3.2	Householders.....	125
2.5.3.3	Architects	125
3	Chapter 3: Understanding Stakeholder Receptivity – Householders, Office Tenants and Architects.....	127
3.1	Introduction	127
3.2	Survey Method	129
3.2.1	Ethical Issues.....	129
3.2.2	Questionnaire design and construction	130
3.2.3	Pilot Study Execution.....	132
3.2.3.1	Pilot Study Results	135
3.2.4	Principal Study	136
3.2.4.1	Participant groups.....	136
3.2.4.2	Follow-up	138
3.2.4.3	Feedback and Follow-up Interviews	139
3.3	Results and Discussion.....	142
3.3.1	Cooperation Rates and Response Bias.....	142

3.3.2	Demographics	143
3.3.3	Experience with Water Saving Devices.....	145
3.3.4	Acceptability of Uses and Associated Risk	148
3.3.5	Current and Future Sources of Information	152
3.3.7	Maintenance Issues	161
3.3.8	Perceived Benefits of RWH.....	167
3.3.9	Experiences with WCs flushed by RWH.....	170
3.3.10	Follow-up Interviews	173
3.3.10.1	Promoting RWH	173
3.3.10.2	Current Promotion.....	174
3.3.10.3	Influence of the questionnaire.....	174
3.4	Questionnaire to Architects.....	175
3.4.1	Questionnaire Design and Construction	175
3.4.1.1	Participants.....	176
3.4.2	Results and Discussion.....	177
3.4.2.1	Awareness of SWM	177
3.4.2.2	Use of SWM.....	178
3.4.2.3	Expertise and Information.....	180
3.4.3	Summary	182
3.5	Chapter Summary and Key Messages.....	182
3.5.1	Summary	182
3.5.2	Key Messages.....	186
4	Chapter 4: Understanding Stakeholder Receptivity – Small to Medium Enterprises.....	188
4.1	Introduction	188
4.2	Interview Method	189
4.2.1	Overview	189
4.2.2	Sampling and Interviewee Identification	189
4.2.3	Arranging and Conducting Interviews.....	191
4.2.4	Interview Guide.....	193
4.2.5	Ecological and External Validity	194
4.3	Analysis.....	196
4.4	Results and Discussion.....	199
4.4.1	Expertise and Advice (E&A)	202

4.4.1.1	Responses and Recommendations	206
4.4.2	Guidance and Support (G&S)	207
4.4.2.1	Responses and Recommendations	209
4.4.3	Confidence and Communication (C&C).....	210
4.4.3.1	Responses and Recommendations	213
4.4.4	Visibility and Access (V&A).....	214
4.4.4.1	Responses and Recommendations	216
4.4.5	Finance and Consultation (F&C)	216
4.4.5.1	Responses and Recommendations	219
4.4.6	Construct Validity of the IDCs	221
4.4.7	Implementer and Non-implementer Differences	222
4.5	Chapter Summary and Key Messages.....	223
5	Chapter 5: Understanding RWH System Performance - Water Quality Assessment.....	225
5.1	Introduction	225
5.2	Case Study and Monitoring Programme	226
5.2.1	Site Characteristics.....	226
5.2.2	Sampling	229
5.2.3	Weather Data.....	232
5.3	Monitoring Programme Results	233
5.3.1	Physicochemical Parameter Results.....	235
5.3.1.1	Nitrogen Results.....	236
5.3.1.2	Chloride Results	237
5.3.1.3	Metal Results.....	241
5.3.1.4	Other Physicochemical Parameter Results.....	245
5.3.2	Microbiological Parameter Results	247
5.3.3	Remedial Action.....	250
5.4	The Impact of Antecedent Weather Conditions.....	251
5.4.1	Antecedent Weather Condition Data Analysis	252
5.4.1.1	Antecedent Weather Condition Statistical Analysis	253
5.4.2	Antecedent Weather Condition Analysis Results	257
5.5	Implementing a Health Impact Assessment (HIA)	261
5.5.1	Quantifying a Health-based Risk	262
5.5.2	HIA and RWH.....	263

5.5.3	HIA of the Innovation Centre RWH System	265
5.2.1.1	Risk Assessment	265
5.2.1.1	Hazard Identification.....	266
5.2.1.1	Exposure Assessment.....	267
5.2.1.1	Quantitative Microbial Risk Assessment.....	267
5.2.1.1	Risk Characterisation	270
5.2.1.1	Health Impact Statement.....	271
5.6	Chapter Summary and Key Messages.....	271
6	Chapter 6: Understanding RWH System Performance – Design and Performance Evaluation	274
6.1	Introduction.....	274
6.2	RWH System Design Evaluation.....	275
6.2.1	Approach.....	278
6.2.2	Site Characteristics.....	279
6.2.2.1	Site 1: Broadclose	279
6.2.2.2	Site 2: Innovation Centre	279
6.2.3	Site 1: Design Evaluation.....	280
6.2.3.1	Catchment Area Limitations	281
6.2.4	Site 2: Design Evaluation.....	284
6.2.4.1	Rainfall Resolution Limitation.....	286
6.2.5	Design Evaluation: Summary and Key Messages	288
6.3	RWH System Performance Evaluation.....	289
6.3.1	Data Collection and Instrumentation	290
6.3.2	Data Analysis	294
6.3.2.1	Innovation Centre BMS Data.....	299
6.3.3	Innovation Centre Water Saving Efficiency	300
6.3.4	Innovation Centre Cost Savings.....	301
6.3.5	Quantifying Energy Consumption by Proxy.....	305
6.3.5.1	An Improved Energy-Carbon Calculation Method.....	306
6.3.5.2	Application of the Improved Method.....	308
6.3.5.3	Innovation Centre RWH System Pump Data.....	308
6.3.5.4	Innovation Centre RWH System Volume Pumped Data.....	309
6.3.5.5	Improved Method and Simplified Method Comparison.....	309
6.3.5.6	Comparison with other studies.....	311

6.3.6	Performance Evaluation: Summary and Key Messages	314
6.4	Non-Domestic WC Demand Profiling and RWH System Design Comparison	315
6.4.1	Measuring Non-Domestic WC Demand	316
6.4.2	Flush Counter Design and Development	316
6.4.2.1	Installation and Testing	319
6.4.2.2	Data Integrity and Flush Counter Limitations	320
6.4.2.3	Summary of Flush Counter Limitations.....	325
6.4.2.4	Processing the Data	325
6.4.2.5	Raw and Processed Data Comparison.....	327
6.4.2.6	One Minute Raw and Processed Data Comparison	327
6.4.2.7	Four Minute Raw and Processed Data Comparison	327
6.4.3	One Minute Processed Data Analysis	330
6.4.4	One Minute Diurnal Rolling Frequency Profiles	331
6.4.5	Four Minute Processed Data Analysis	332
6.4.6	Four Minute Diurnal Rolling Frequency Profiles	334
6.4.7	Non-Domestic WC Demand Frequency Profile	335
6.4.8	Non-Domestic RWH System Design Comparison	338
6.4.9	Non-Domestic WC Demand Profiling with RWH System Design Comparison: Summary and Key Messages.....	340
6.5	Chapter Summary and Key Messages.....	341
7	Chapter 7: Integrating Insights - Building The Strategic Framework.....	343
7.1	Introduction	343
7.2	Summary of Key Messages.....	344
7.2.1	Chapter 3:	344
7.2.2	Chapter 4:	345
7.2.3	Chapter 5:	345
7.2.4	Chapter 6:	346
7.3	Strategy Areas	347
7.3.1	Product Development.....	349
7.3.1.1	Recommendation.....	352
7.3.2	Capacity Building	352
7.3.2.1	Recommendation.....	356
7.3.3	Support Services	357
7.3.3.1	Recommendation.....	359

7.4	The Strategic Framework.....	360
7.4.1	Implementing the Framework – Guidance for Stakeholders	361
8	Chapter 8: Conclusion, Impact Plan and Further Research	363
8.1	Conclusion	363
8.2	Impact plan.....	366
8.3	Further Research	367
8.3.1	Product Innovation	367
8.3.2	Undertake a Charrette	367
8.3.3	3D Visualisation of ‘RWH Buddies’	367
8.3.4	Tank Sediment Quality study.....	367
8.3.5	Technical Impacts on Demand Behaviour	368
8.3.6	Demand Profiling.....	368
8.3.7	Micro-renewable Energy Generation.....	368
8.3.8	Apply the ESTEEM/SOCROBUST Methodology	369
	References	370
	Appendix A – List of Publications	391
	Appendix B – Chapter 3.....	393
	Appendix C – Chapter 4.....	450
	Appendix D – Chapter 5.....	478
	Appendix E – Chapter 6.....	492

LIST OF FIGURES

Figure 1.1 Disciplinary perspectives informing the philosophical viewpoint and design of the research and their level of operation.....	29
Figure 1.2 Overview of the aim, objective and general methods used in the research design	33
Figure 1.3 Flow chart summarising connections between the aim, objectives, methods and chapters of this thesis	39
Figure 2.1 Conceptual model of urban integrated water cycle management and related concepts in Australia	41
Figure 2.2 Water Availability ¹ in England and Wales, Summer (A) and Winter (B)	48
Figure 2.3 Measured (A) and Unmeasured (B) Per Capita Consumption (litres).....	48
Figure 2.4 UK metering penetration by region (actual, 2004 and projected 2009)	49
Figure 2.5 Per capita consumption and metering penetration across the globe	49
Figure 2.6 Domestic water consumption in England & Wales and Germany	50
Figure 2.7 Comparison of consumption in England & Wales and Germany.....	52
Figure 2.8 Micro-component water use for two building types.....	52
Figure 2.9 The SUDS Surface Water Management Train	56
Figure 2.10 Chultun and paved catchment area	57
Figure 2.11 Effect of RWH on Design Storm Peak Volume	62
Figure 2.12 Innovative ‘plastic bag’ RWH system used in Asia	65
Figure 2.13 Basement and above ground RWH tanks in Australia	66
Figure 2.14 Components of the innovative ‘plastic bag’ RWH system.....	71
Figure 2.15 External view and cross-section of the ENVISS Sentinel 450 system.....	72
Figure 2.16 External view and cross-section of the ‘gutter’ storage RWH system	72
Figure 2.17 The ‘ARC’ RWH system under development in the UK	73
Figure 2.18 Domestic micro-component diurnal wastewater discharge profile	75
Figure 2.19 A sign for assisting in the prevention of cross-connections	87
Figure 2.20 Schematic and demonstration of a Japanese Rojison community RWH system.....	96
Figure 2.21 Schematic and artistic impression of the Tokyo Sky Tree	96
Figure 2.22 The RWH contracting model in Germany.....	97
Figure 2.23 Emscher’s ‘Rainwater Route’	98
Figure 2.24 Rainwater and infiltration projects in Emscher	98
Figure 2.25 Schematic of the BASIX water module.....	101

Figure 2.26 The S-curve model of technology diffusion (A) and adopter groups throughout the diffusion process (B).....	111
Figure 2.27 The nested hierarchy of a technology transition.....	113
Figure 2.28 The position of receptivity between policy and marketing	116
Figure 2.29 The social research theoretical framework developed in this thesis	123
Figure 2.30 categories of definition for SMEs.....	124
Figure 3.1 User interface of the APART questionnaire design software.....	131
Figure 3.2 Participant interface for the questionnaire.....	131
Figure 3.3 The Broadclose development	140
Figure 3.4 The Innovation Centre Phase II	140
Figure 3.5 The Littleham development.....	140
Figure 3.6 The Innovation Centre Phase I	140
Figure 3.7 Map of questionnaire and interview locations.....	141
Figure 3.8 Gender of participants.....	144
Figure 3.9 Age distribution of the participants	144
Figure 3.10 Occupancy status of residential location participants.....	145
Figure 3.11 Number of occupants per household in residential locations	145
Figure 3.12 Participants experiences with water saving devices	146
Figure 3.13 Exposure to using a RWH system	147
Figure 3.14 ICP2 experiences with water saving devices.....	147
Figure 3.15 Acceptability of sources for reuse	149
Figure 3.16 Uses for which participants would consider RWH.....	149
Figure 3.17 Average 'risk' associated with different RWH end uses.....	150
Figure 3.18 User and non-user average 'risk' associated with different RWH end uses	151
Figure 3.19 Plot comparing the range of risk ratings for RWH system users and non-users	151
Figure 3.20 Have you ever obtained information on RWH?	152
Figure 3.21 How would wider availability of information affect your consideration of installing a RWH system?.....	153
Figure 3.22 Where would be the best place to access information on RWH?.....	153
Figure 3.23 RWH system user and non-user responses to factors encouraging consideration of RWH.....	156
Figure 3.24 Participant claims regarding environment and water conservation.....	159
Figure 3.25 Factors encouraging consideration of installing RWH.....	159

Figure 3.26 Do you think RWH is a good thing?	161
Figure 3.27 Participants' consideration of the importance of maintenance.....	162
Figure 3.28 Perceived frequency for conducting RWH maintenance activities	162
Figure 3.29 Perceived frequency for conducting RWH maintenance activities	164
Figure 3.30 RWH system users' knowledge of maintenance provision	164
Figure 3.31 Participant ranks of the importance of cleaning the RWH catchment for system function (SF) and water quality (WQ).....	165
Figure 3.32 Perceptions of maintenance activity costs between users and non-users ..	166
Figure 3.33 Participants' perceptions of the benefits of RWH (users and non-users)..	168
Figure 3.34 Participants' perceptions of the benefits of RWH (different locations)	169
Figure 3.35 Differences in WC performance and aesthetics observed by participants	170
Figure 3.36 Overall satisfaction with WCs flushed by RWH.....	171
Figure 3.37 How participants felt about WC performance differences	171
Figure 3.38 Participant's awareness of SWM techniques.....	178
Figure 3.39 Participants rating of the success of projects involving SWM.....	180
Figure 3.40 Expertise and documentation use in the participating practices.....	180
Figure 4.1 Implementation Deficit Categories and their interaction with RWH stakeholders.....	200
Figure 4.2 Variation in Percentage of Content within each Interview for the 5 IDCs for Implementers (I) and Non-Implementers (N)	223
Figure 5.1 Aluminium and bitumastic-felt sections of the Innovation Centre roof catchment	227
Figure 5.2 Downpipe and hopper and the main storage tank under the Innovation Centre car park.....	227
Figure 5.3 Exterior and Interior of the Innovation Centre RWH system control panel	227
Figure 5.4 800L GRP header tank and associated pipework (including meters).....	228
Figure 5.5 440µm pre-tank coarse debris and 180µm in-tank floating suction filters..	228
Figure 5.6 35µm inline backwashing filter	228
Figure 5.7 Schematic of the RWH system, including sampling point location (6)	229
Figure 5.8 Original (A) and replacement (B) sampling apparatus on the RWH outlet	230
Figure 5.9 Different types of sample bottle used in the monitoring programme.....	232
Figure 5.10 Snow on the Innovation Centre roof (RWH system catchment area)	232
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.....	237

Figure 5.12 Temporal variability of chloride concentrations and comparison with the British Standard value	238
Figure 5.13 Average weekly (7-day) prevailing wind directions for the Innovation Centre (% of total number of incidences)	239
Figure 5.14 Plot illustrating the range of chloride concentrations for each wind direction, including extreme values	241
Figure 5.15 Plot illustrating the range of chloride concentrations for each wind direction, without extreme values	241
Figure 5.16 Temporal variability of calcium, chloride, sodium, potassium and silicate concentrations	243
Figure 5.17 Temporal variability of metal concentrations in comparison with chloride concentrations and the WHO (2008) guideline levels (where given)	244
Figure 5.18 Temporal variability of pH values and comparison with the British Standard values.....	246
Figure 5.19 Total coliform, Faecal coliform and <i>E. faecalis</i> counts (log) in comparison with guideline values.....	248
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)	251
Figure 5.21 The heavy positive skew of the <i>E. faecalis</i> 24 hour dataset	254
Figure 5.22 The range of <i>E. faecalis</i> counts for dry and wet periods for the 24 hour antecedent duration, including outliers and extreme values	254
Figure 5.23 The normalised (log ₁₀ transformed) <i>E. faecalis</i> 24 hour dataset	255
Figure 5.24 The log ₁₀ transformed range of <i>E. faecalis</i> counts for dry and wet periods for the 24 hour antecedent duration	256
Figure 5.25 The HIA Procedure.....	262
Figure 6.1 Differences in actual and estimated tank sizes, for Site 1	284
Figure 6.2 Differences in actual and estimated tank size, for Site 2.....	285
Figure 6.3 30-year standard average monthly rainfall data for Teignmouth	287
Figure 6.4 Innovation Centre water meters with remote monitoring wiring	290
Figure 6.5 Regression analysis for depression storage and runoff coefficient	295
Figure 6.6 Total weekly WC mains water and rainwater consumed volumes for the Innovation Centre.....	297
Figure 6.7 Cumulative runoff, overflow, total WC demand, rainwater and mains water top-up consumed for the Innovation Centre.....	297

Figure 6.8 Cumulative total WC demand, rainwater and mains water top-up consumed for the Innovation Centre West and East wings.....	298
Figure 6.9 Daily and cumulative harvested rainwater and mains water consumption data from the Innovation Centre BMS (19-23rd October 2009)	300
Figure 6.10 Water Saving Efficiency (E_T) of the Innovation Centre RWH System compared with modelled values.....	301
Figure 6.11 Graphical User Interface of the RWH System Pump Energy and Carbon Tool	310
Figure 6.12 Variability of energy consumption values attributed to centralised WDS and decentralised RWH in a variety of locations.....	313
Figure 6.13 Comparison of sources of household energy consumption, including RWH	313
Figure 6.14 Float switch and digital interface of the flush counter	317
Figure 6.15 Internal components of the flush counter and the device <i>in situ</i>	318
Figure 6.16 Dimensions of and water levels within the cisterns to which the flush counters were fitted (measurements in mm).....	318
Figure 6.17 Graphical User Interface of the Multilog software.....	318
Figure 6.18 Schematic of the locations of the flush counters within the Innovation Centre	319
Figure 6.19 Excerpt of a raw data file for input 1 (total flushes) for flush counter F1030	322
Figure 6.20 The effect of multiple button pressing within a time step	324
Figure 6.21 The ambiguity caused by the refilling of a flush across two (or more) time steps.....	324
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.....	328
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	328
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.....	328
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.....	329
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	329

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.....	329
Figure 6.28 Inter-counter/male (M) and female (F) differences between full and partial flushing at the one minute time step	331
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	333
Figure 6.30 Inter-counter/male (M) and female (F) differences between full and partial flushing at the four minute time step.....	334
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	336
Figure 6.32 Diurnal full and partial flush frequency profiles averaged across five flush counters and 46 days	337
Figure 6.33 Diurnal full and partial flush volume consumed profiles averaged across five flush counters and 46 days.....	337
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.....	337
Figure 7.1 The Strategic Framework for RWH	360

LIST OF TABLES

Table 1.1 Roles assumed by the author in relation to research methods utilised.....	36
Table 2.1 Chronology of the main published documents related to SWM in the UK over the last ten years	46
Table 2.2 Water consumption star ratings for PCC/day under the CfSH	51
Table 2.3 Summary of studies into assessing the efficiency of RWH systems	60
Table 2.4 Hydraulic configurations for RWH Systems	67
Table 2.5 Pumping configurations for RWH Systems.....	68
Table 2.6 Advantages and disadvantages of above ground and below ground RWH storage	69
Table 2.7 Summary and description of conventional RWH system components.....	70
Table 2.8 Summary of RWH system sizing methods	76
Table 2.9 Existing models for analysing RWH systems.....	78
Table 2.10 Summary of previous rainwater quality studies.....	81
Table 2.11 Summary of recent harvested rainwater quality studies	83
Table 2.12 Summary of microbiological studies	85
Table 2.13 Parameters for RWH monitoring within the British Standard.....	89
Table 2.14 Preventative measures to optimize water quality.....	90
Table 2.15 Recommended frequency of maintenance activities in BS 8515:2009	90
Table 2.16 Summary of barriers to RWH implementation	91
Table 2.17 Summary of state ambitions for water resource management.....	100
Table 2.18 Percentage of RWH penetration in Australian states.....	101
Table 2.19 Comparison of the features of the UK RWH sector with other countries ..	104
Table 2.20 Demonstrating the relevance of the receptivity framework to RWH	116
Table 3.1 Summary of the sections within the finalised questionnaire	136
Table 3.2 Summary of characteristics for the questionnaire sample locations	137
Table 3.3 Cooperation rates for each questionnaire location.....	142
Table 3.4 Results of tests for data normality.....	150
Table 3.5 Factors and references for Figure 3.23.....	155
Table 3.6 Factors encouraging RWH ranked by number of responses received	160
Table 3.7 Recommended frequency of maintenance activities (BSI, 2009).....	163
Table 3.8 T-test results for participant responses regarding RWH maintenance costs.	165
Table 3.9 Univariate ANOVA results for non-user responses regarding RWH maintenance costs.....	166

Table 3.10 Benefits of RWH suggested to participants and their references on Figure 3.33 and Figure 3.34	167
Table 3.11 Univariate ANOVA results for the effect of location on response chosen to a question on the benefits of RWH.....	168
Table 3.12 Participants rating of WC performance and aesthetics (%).....	171
Table 3.13 ‘Negative’ comments received on aspects of WC performance (%).....	172
Table 3.14 Location of the practitioners contacted.....	176
Table 3.15 Key to labels on Figure 3.38	177
Table 3.16 Details of projects using SWM provided by participants	179
Table 3.17 Participants knowledge and use of guidance documentation	182
Table 4.1 Characteristics of the interviewed SME sample	192
Table 4.2 Interview Guide Topics.....	195
Table 4.3 Percentage of content allocated to each Implementation Deficit Category (and ‘other’ categories) within the 7 interviews.....	221
Table 5.1 Summary of the quality of harvested rainwater samples collected weekly ..	234
Table 5.2 Summary of the quality of harvested rainwater samples collected every three months.....	235
Table 5.3 Results of the Pearson’s Product Moment statistical analysis between microbiological parameters and pH	249
Table 5.4 The number of dry (<5mm rainfall) and wet (>5mm rainfall) events during the monitoring duration for different antecedent durations	253
Table 5.5 Summary of data transformations and statistical tests applied to each parameter in relation to antecedent weather condition	257
Table 5.6 Statistical test results for each parameter and antecedent duration.....	258
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	264
Table 5.8 Age profile of the Innovation Centre study population	265
Table 5.9 QMRA data requirements for calculating the DALY for <i>E. faecalis</i> via WC flushing.....	269
Table 5.10 @Risk input values	269
Table 5.11 Risk characterisation summary for the Innovation Centre RWH system with comparators	270
Table 6.1 Characteristics of Site 1 and Site 2	280
Table 6.2 RWH system supplier design parameters and author calculated values for Site 1.....	281

Table 6.3 Comparison of results for each home zone (HZ) in Site 1 using each method	283
Table 6.4 RWH system supplier design parameters and values for Site 2	284
Table 6.5 Method 1 results using different rainfall data for Site 2	287
Table 6.6 Innovation Centre RWH system fault log chronology	292
Table 6.7 Potential overflow events from the Innovation Centre RWH system.....	296
Table 6.8 Weekly cost savings associated with mains water supplemented by harvested rainwater for the Innovation Centre	304
Table 6.9 Parameters and their values used to calculate energy consumption and CO ₂ emissions of the Innovation Centre RWH system	308
Table 6.10 Pump rating and capacities for a rainwater harvesting system pump (modified from Roebuck, 2008).....	309
Table 6.11 Monthly rainwater volumes supplied by the Innovation Centre RWH system	309
Table 6.12 Results of the Improved Method Compared with the Simplified Method..	310
Table 6.13 Cost of electricity associated with RWH pumping for the Innovation Centre	311
Table 6.14 Example of normal and erroneous data from flush counter F1030.....	321
Table 6.15 Quantifying the error associated with the flush counter limitations	326
Table 6.16 T-test results for gender differences of full and partial flushing.....	330
Table 6.17 T-test results for gender differences of full and partial flushing.....	334
Table 6.18 Total and Average Daily Number of Flushes for the Innovation Centre....	335
Table 6.19 Results of the domestic versus non-domestic system design comparison..	340
Table 7.1 Comparison between Geel’s historic shipping technology transition analysis and the author’s analysis of RWH in the UK.....	348
Table 7.2 Example Actors and Actions for Implementing the Strategic Framework...	362

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 Gesellschaft für Nachhaltiges Bauen	
DI	Diffusion of Innovation	
DIN	Deutsches Institut für 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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