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

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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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