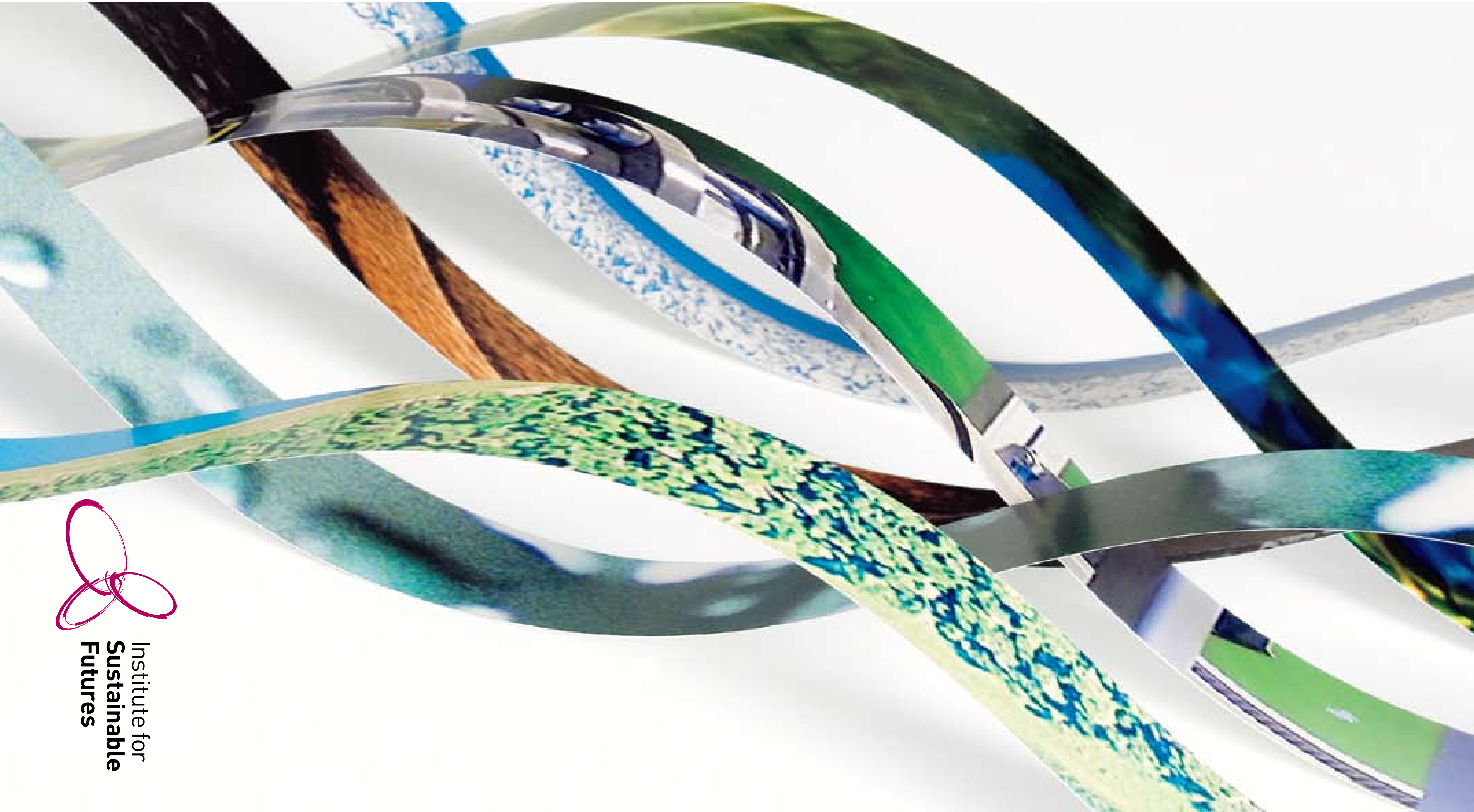
INSTITUTE FOR SUSTAINABLE FUTURES

THINK.
CHANGE.
DO

ISF: RESEARCH

THE WATER-ENERGY NEXUS: INVESTIGATION INTO THE ENERGY IMPLICATIONS OF HOUSEHOLD RAINWATER SYSTEMS



Institute for Sustainable Futures

UNIVERSITY OF TECHNOLOGY SYDNEY

THE WATER-ENERGY NEXUS

Investigation into the Energy Implications of Household Rainwater Systems

Final Report

For CSIRO

Authors

Monique Retamal, John Glassmire, Kumi Abeysuriya,

Andrea Turner and Stuart White

Institute for Sustainable Futures

DISCLAIMER

DOCUMENT REVIEW

Revision	Date	Prepared by:	Reviewed by:
Revision 1 (Draft)	25/03/09	Monique Retamal	Andrea Turner, Stuart White
Revision 2 (Final Report)	15/05/09	Monique Retamal	Andrea Turner
Revision 3 (Final Report with minor amendments)	4/11/09	Monique Retamal	Andrea Turner

ACKNOWLEDGEMENTS

Funding for this project was provided by CSIRO, under the Collaboration Fund for the Water for a Healthy Country Flagship.

The authors would like to thank the following people for their contribution to this study:

- CSIRO and other research colleagues including: Matthew Inman, Alan Gregory, Ashok Sharma, Murray Hall, Tim Baynes and Ted Gardner for their valuable input,
- John Caley and Bernard Hockings for their assistance with field work and field observations,
- Peter Henry at Testing Certification Australia (TCA) for developing a meter and data logger system to meet our requirements,
- The householders who kindly allowed us to monitor their rainwater systems.

Please cite this report as follows:

Retamal, M., Glassmire, J., Abeysuriya, K., Turner, A., White, S., 2009, *The Water-Energy Nexus: Investigation into the Energy Implications of Household Rainwater Systems*, [prepared for CSIRO], Institute for Sustainable Futures, University of Technology, Sydney.

TABLE OF CONTENTS

DISCLAIMER I

DOCUMENT REVIEW I

ACKNOWLEDGEMENTS I

TABLE OF CONTENTS II

LIST OF FIGURES V

LIST OF TABLES VII

EXECUTIVE SUMMARY VIII

1 INTRODUCTION 1

1.1 The project 1

1.2 Project background 1

1.3 This document 2

2 CONTEXT 4

2.1 A new era in water systems 4

2.2 Water efficiency and source substitution 6

2.3 A potential problem 8

3 OVERVIEW OF ENERGY USE IN THE WATER SECTOR 9

3.1 Conventional large-scale systems 9

3.2 New large-scale systems 10

3.3 Hot water usage and water efficiency 11

3.4 Emerging decentralised systems 11

4 STUDY SCOPE 15

4.1 Data availability 15

4.2 Revised scope 15

5 RAINWATER TANK SYSTEMS 19

5.1 Typical configurations 19
5.2 System elements – potential issues and solutions 21
5.2.1 Storage 21
5.2.2 Pump 22
5.2.3 Mains water backup 24
5.2.4 Plumbing 25
5.2.5 Rainwater Treatment 26
5.2.6 Pressure Assistance 26
6 THEORETICAL ANALYSIS 29
6.1 Water Usage Data 29
6.2 Pump Models 29
6.2.1 General Model Assumptions 30
6.2.2 Constant-Power Model 30
6.2.3 Pump models developed from pump test data 32
6.2.4 Results from Pump models 33
6.2.5 Discussion 35
7 EMPIRICAL ANALYSIS 36
7.1 Test site descriptions 36
7.2 Metering Equipment 44
7.3 Metering Results 44
7.3.1 Energy and water consumption 44
7.3.2 Key observations from empirical results 47
7.3.3 Analysis by end use 49
8 DISCUSSION OF THEORETICAL AND EMPIRICAL RESULTS 53
8.1 Comparison of Theoretical and Actual Energy Intensities 53
8.2 Further Investigation required 54
9 POTENTIAL BROAD-SCALE IMPLICATIONS 56

9.1 Implications for city wide use of ralnwater systems 56

9.2 Implications for pump design 57

10 SUMMARY AND WAY FORWARD 60

10.1 Summary of findings 60

10.2 Research gaps 62

11 REFERENCES 63

APPENDIX A: PUMP EFFICIENCY 65

APPENDIX B: BREAKDOWN OF PUMP LOSSES 67

APPENDIX C: PUMP POWER CURVES USED IN THEORETICAL MODELLING 70

LIST OF FIGURES

Figure 2-1 Conventional Water Cycle – Macro and Micro Scale 4

Figure 2-2 Emerging Water Infrastructure – Macro and Micro Scale 5

Figure 2-3 Potential number of rainwater tanks in BASIX houses in NSW due to BASIX program alone 7

Figure 3-1 Silva Park Schematic from Beal et al. 2008 12

Figure 3-2 Energy intensity of water system components at Silva Park (Beal et al 2008)..... 13

Figure 5-1 Schematic of a simple household rainwater system for outdoor use 19

Figure 5-2 Common rainwater system configuration using a trickle top up 20

Figure 5-3 Common rainwater system configuration using a mains switch 20

Figure 5-4 Example of a domestic rainwater storage tank 22

Figure 5-5 Example of a domestic rainwater pump 23

Figure 5-6 Example of an automatic switching system commonly used for domestic applications 25

Figure 5-7 Example of a large domestic pressure vessel used as part of a rainwater supply system 27

Figure 6-1 Power Curve for the Constant-Power Pump Model 31

Figure 6-2 Example plot of constant-power pump flow rate and power consumption versus time 31

Figure 6-3 Example of a pump power curve for a rainwater tank pump (Davey Water Products, 2008) 32

Figure 6-4 Typical plot of Pump 2 flow rate and power consumption versus time 33

Figure 7-1 Balmain House system schematic 36

Figure 7-2 Newtown house system schematic 37

Figure 7-3 Newcastle House No. 1 system schematic 38

Figure 7-4 Newcastle House No. 2 system schematic 38

Figure 7-5 Padstow house system schematic 39

Figure 7-6 Redfern Office system schematic 39

Figure 7-7 Enmore Terrace system schematic 40

Figure 7-8 Concord House system schematic 41

Figure 7-9 Rainwater systems configurations map showing tests represented in this study 42

Figure 7-10 Rainwater system testing diagram with measured energy intensities at each site 46

Figure 7-11 Energy intensity and daily household water and energy consumption for households using rainwater for non-potable end uses (toilet, outdoor, laundry) 50

Figure 7-12 Daily water and energy consumption per person for households using rainwater for non-potable end uses (toilet, outdoor, laundry) 50

Figure 7-13 Energy intensity and daily household water and energy consumption for households using rainwater for all domestic end uses 52

Figure 7-14 Daily water and energy consumption per person for households using rainwater for all domestic end uses 52

Figure 9-1 Projected energy demand due to BASIX rainwater tanks.. 57

Figure 9-2 Summary of pump efficiency and losses in a rainwater system 58

LIST OF TABLES

TABLE 3-1 AVERAGE ENERGY INTENSITIES OF STEPS IN THE CALIFORNIAN WATER CYCLE (COHEN ET AL. 2004) 9

TABLE 3-2 SUMMARY OF ENERGY INTENSITIES ASSOCIATED WITH WATER TREATMENT, SUPPLY AND WASTEWATER DISPOSAL IN CITIES AROUND AUSTRALIA DURING 2006/07 (KENWAY ET AL. 2008) 10

TABLE 3-3 ENERGY INTENSITY OF WATER SUPPLY BEFORE AND AFTER LARGE-SCALE SYSTEM AUGMENTATION IN SYDNEY, PERTH AND ADELAIDE (KENWAY ET AL, 2008) 11

TABLE 3-4 CHARACTERISTICS OF THE RAINWATER SYSTEM AT SILVA PARK 12

TABLE 3-5 RATIO OF ON-LOT TANK VOLUMES TO TOTAL WATER USE 14

TABLE 4-1 ORIGINAL LIST OF POTENTIAL CASE STUDIES FOR EVALUATION OF ENERGY RELATED TO EMERGENT WATER SERVICE INFRASTRUCTURES 16

TABLE 5-1 RANGE OF RAINWATER SYSTEM COMPONENTS 21

TABLE 6-1 CALCULATED ENERGY INTENSITIES OF RAINWATER PUMPING SYSTEMS FOR THREE HOUSES USING FOUR PUMP MODELS 34

TABLE 6-2 RESULTS FROM FOUR MODELS ESTIMATING AVERAGE HOUSEHOLD RAINWATER SYSTEM ENERGY INTENSITY 34

TABLE 7-1 FEATURES OF THE RAINWATER SYSTEMS, END USES AND USERS AT EACH TEST SITE (NOTE: ALSO CONTINUED ON THE NEXT PAGE) 43

TABLE 7-2 MONITORING RESULTS – AVERAGE ENERGY INTENSITY OF RAINWATER SYSTEM CONFIGURATIONS 45

TABLE 7-3 WATER USE CHARACTERISTICS OF THREE HOUSEHOLDS WITH SIMILAR RAINWATER SYSTEM CONFIGURATIONS 49

TABLE 8-1 COMPARISON BETWEEN CALCULATED AND MEASURED ENERGY INTENSITIES 53

EXECUTIVE SUMMARY

This report describes the results of a collaborative research project undertaken by the Institute for Sustainable Futures, at the University of Technology Sydney, for CSIRO, as part of the Water for a Healthy Country Flagship Collaboration Fund. The objective of the research project has been to examine the energy implications of emerging distributed water infrastructure, the 'water energy nexus'.

The first phase of this work included a broad literature review of existing research into the water energy nexus, followed by a scoping paper identifying key areas for further research. A number of lot- and estate-scale water systems at sites around Australia were selected as potential case studies and the intention was to conduct a desktop review of their water and energy implications. However, preliminary research showed that existing data was scarce or non-existent. It was therefore decided to complement the research project by carrying out primary research focusing on lot-scale rainwater systems. This additional research has focussed on detailed monitoring and measurement of the energy and water use of eight household systems in Sydney and Newcastle to determine the empirical energy intensity of their rainwater tank systems. In addition, a model has been developed that uses empirical time series water demand data, and actual flow versus power curves for typical rainwater tank pumps to estimate the energy intensity for different pump and end use combinations.

Existing research into the energy use of water infrastructure has primarily focused on large-scale centralised systems, hence, the energy intensity of different aspects of these systems is reasonably well understood. However, there is currently considerable investment in new lot- and estate-scale water infrastructure, including precinct-scale water recycling plants, stormwater harvesting systems, household rainwater tanks and household greywater re-use systems. To date, very little evaluation of these systems has been carried out and the actual operating energy consumption and even water savings of these systems have been the subject of limited investigation.

Household rainwater systems in particular have become increasingly prevalent and their uptake is being encouraged by state and federal government policies. Rebates are being offered to households installing rainwater and greywater systems and in addition, state legislation such as BASIX in NSW requires all new households to reduce their water consumption by up to 40% (depending on location) and over 90% of these households are opting to install a rainwater tank.

This research project has found that the typical energy intensity of the most common single household rainwater tank system has an energy intensity of approximately 1.5 kWh/kL, which compares to a typical figure of less than 1 kWh/kL, for centralised water supply systems and a figure of over 4 kWh/kL for water from large-scale desalination plants. The absolute energy use of a household with a rainwater system will depend on the level of water efficiency of the household.

The energy intensity of water use from rainwater tank systems is very dependent on the pump size, the system configuration, the level of water efficiency and the end-uses to which the tank is connected. End uses that have a low flow, such as toilet cistern refilling, faucet use and leaks have higher energy intensities than end uses such as showers, outdoor water use and bath filling which are typically high-flow end uses. As part of this research project an overall estimate of the energy implications of the large-scale installation of rainwater tank systems has been investigated for Sydney using the data and information collated to provide a comparison with a typical mains water supply system.

This research has identified the need for further measurement of the in-situ energy intensity of different rainwater tank system configurations, to test the impact of pressure vessels, rain switches and variable speed pumps and to estimate the relative cost of these options. There is also a gap in the research regarding appropriate forms of guidelines or policy instruments to encourage best practice efficiency for rainwater tank pumps. Finally, there is a need for further investigation of more complex configurations of distributed water infrastructure including systems in multi-residential and commercial buildings, distributed effluent treatment and reuse systems and neighbourhood scale systems.

By filling these additional research gaps and using standards, guidelines and policy instruments to embed best practice efficiency in rainwater systems and broader water and wastewater distributed systems, the water industry will be able to avoid locking in inefficient systems and tap into the full potential these systems can provide.

1 INTRODUCTION

1.1 THE PROJECT

In April 2008 CSIRO commissioned the Institute for Sustainable Futures (ISF), part of the University of Technology Sydney (UTS), to undertake this research project examining:

"the water energy nexus for sustainable water futures: uncovering the water and energy implications of lot and estate scale water efficiency and source substitution"

This report summarises the findings of the research project undertaken. The research was initially broad in nature but due to the current major policy decisions being made, significant data gaps found and preliminary research observations, it was decided to focus primarily on the energy intensity of rainwater tank configurations at the lot scale within the broader water-energy nexus context.

It is intended that this research assist much-needed further investigation in this field and provide background information for policy makers, researchers and practitioners involved in planning and managing future water service provision, which involves distributed urban water efficiency and source substitution.

1.2 PROJECT BACKGROUND

In 2006, staff at ISF and CSIRO were heavily involved in research associated with water efficiency and distributed water and wastewater systems in urban water planning across Australia. At this time, a concern was raised that the energy usage within such systems could potentially be higher than more conventional water service provision and that a focus on both potable water savings and the energy implications of such systems was needed to inform water and energy policy decisions. Subsequent discussions lead to ISF submitting a proposal in early 2007 to the CSIRO flagship collaboration fund – Water for a Healthy Country. This research project was subsequently commissioned in April 2008.

The original research proposal identified three key areas of research:

1. **Individual appliance scale** – The trade-off between water and energy use by individual appliances to achieve the same service. The uptake of cooling appliances, for example evaporative versus refrigerative air conditioners or cooling towers versus air cooling, has significant potential to alter the energy and water intensity of the provided service. Therefore quantifying and assessing these trade-offs can provide important information for resource planning and determining the benefits of different service provision options. This can also be considered more broadly to investigate whether there are other means of achieving the same service – for example, passive design in houses and the use of more energy-efficient appliances in commercial buildings to reduce ambient temperature and therefore air conditioning load.

2. **Lot and estate scale** – Determining actual water and energy savings attained by water-efficient appliances in multiple configurations and real-life applications and through the installation of rainwater tanks and greywater systems for both individual lots and at an estate scale. There is some evidence to suggest that the water savings obtained from rainwater tanks are not as high as expected (i.e. 20 kL/household/a) (Snelling et al. 2006; Turner 2007) and that the energy use intensity could be higher than it is for major supply-side options (Gardner et al. 2006). If this is true, the water industry needs to be made aware of these findings and guidance provided on how to measure water and energy usage, maximise water savings, lower costs and limit any increase in energy usage. This would improve the feed-

back loop of such configurations and ensure that the full potential of these demand management options is realised.

3. **City-wide scale** – Modelling energy and water tradeoffs. Detailed modelling utilising end use analysis (disaggregation of water to end uses such as showers, toilets and washing machines) is now more commonly used to forecast water demand and develop demand management options. This approach enables comparison against supply-side options and to determine how best to fill the supply-demand gap. In many cases such modelling considers the energy intensity of the current system and how water efficiency, source substitution, re-use and supply options can potentially save/use more water and energy. However, whilst the detail of the water modelling may be rigorous, the energy component of such modelling is not. Further, while the embodied energy in water supply is often considered, the embodied water in energy supply is seldom quantified and taken into account from a planning perspective. Due to the importance of resource managers understanding the trade-offs between water and energy, system-wide modelling accounting for these elements needs further research to build on the existing models and to aid truly informed resource management decisions.

This research project has prioritised the second of the above three areas due to:

- the current momentum behind policy direction and investment in water efficiency and potable source substitution initiatives at both the individual lot and estate scale;
- the significant resource efficiency opportunities that could be realised if water and source substitution are designed and implemented well; and
- the serious economic and resource use implications if decisions are made with limited and/or incorrect information on the water and energy savings being achieved by such initiatives.

As previously indicated, this research project was initially broad in nature but has focussed primarily on the energy intensity of rainwater tank configurations at the lot scale within the broader water-energy nexus context.

1.3 THIS DOCUMENT

This document is accompanied by a preliminary literature review and a scoping paper, which were used to provide discussion material for an internal workshop undertaken with CSIRO in July 2008 to set the direction of this research project.

This document summarises the research undertaken and the associated findings and is split into the following chapters:

- Chapter 2 – *Context* – Provides an outline of the project context, including recent changes to the urban water cycle
- Chapter 3 – *Overview of Energy Usage in the Water Sector* – Is a summary literature review on previous studies that have investigated the energy usage of water infrastructure
- Chapter 4 – *Study Scope* – Sets out the original scope and revised scope of the study
- Chapter 5 – *Rainwater Systems* – Explains the rainwater system elements and their potential impacts on overall system energy use

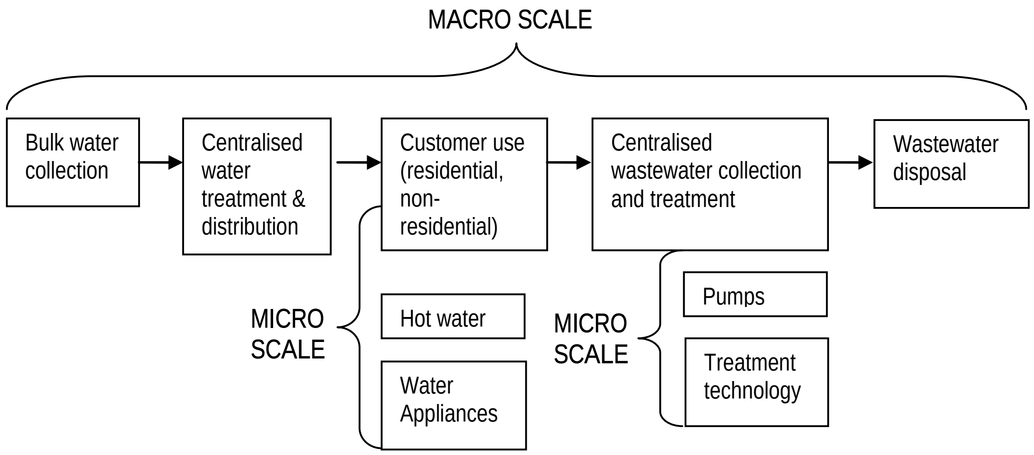
- Chapter 6 – *Theoretical Analysis* – Explains the approach to modelling the theoretical energy consumption of household rainwater systems and tables the results
- Chapter 7 – *Empirical Analysis* – Sets out the details of the household rainwater systems that were monitored and discusses key observations from the results
- Chapter 8 – *Discussion of Theoretical and Empirical Results* – Provides a comparison between the energy intensities that were calculated in the theoretical analysis and the practical results that were recorded
- Chapter 9 – *Potential Broad Scale Implications* – Discusses the potential energy implications of inefficient rainwater pumping systems being rolled out over the next 30 years and what might be done to improve pumping systems
- Chapter 10 – *Summary and Way Forward* – Lists key recommendations arising from this study and set out future research questions.

2 CONTEXT

2.1 A NEW ERA IN WATER SYSTEMS

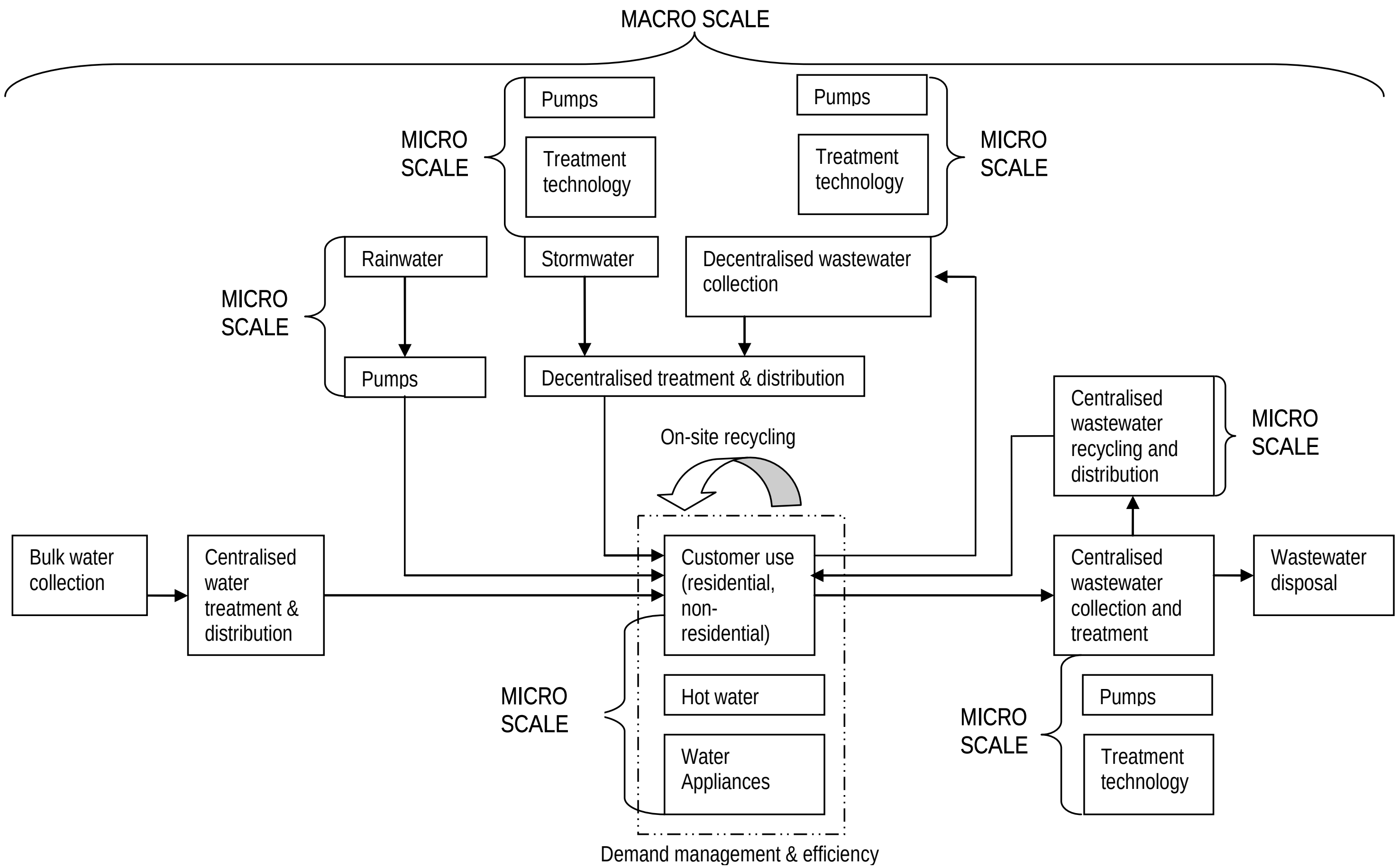
Historically, urban water systems have been fairly simple and linear in nature: water is typically obtained from a large surface water dam and/or groundwater source, treated and distributed to customers and the resulting effluent collected, treated and disposed of as illustrated in Figure 2.1.

Figure 2-1 Conventional Water Cycle – Macro and Micro Scale



However, due to prolonged droughts and the threat of climate change, more risk-averse supply options with less surface water dependency (e.g. desalination plants) are now being included in the portfolio of supply sources together with major reuse systems. In addition, there has been a significant increase in the contribution of water efficiency and source substitution distributed systems (e.g. rainwater tanks and greywater systems) to the portfolio of options used to fill the supply-demand gap (as illustrated in Figure 2.2.).

Figure 2-2 Emerging Water Infrastructure – Macro and Micro Scale



2.2 WATER EFFICIENCY AND SOURCE SUBSTITUTION

In the residential sector, which generally represents over half the water demand in a city, increases in water efficiency and source substitution are being achieved through various means such as:

- mandatory efficiency standards for individual appliances;
- provision of rebates and retrofits at a household level; and
- implementation of regulations to increase the efficiency of new and refurbished households resulting in the reconfiguration of potable water, rainwater and effluent infrastructure at a lot and estate scale.

In several jurisdictions across Australia significant investment in retrofits and rebates for water efficient appliances has been made (i.e. Perth, South East Queensland and Sydney) which is causing a major shift in the number of efficient appliances. For example in Sydney, in the longest running major demand management program in Australia, nearly 400,000 households (out of over 1.5 million households) have taken part in the Sydney Water Corporation (SWC) WaterFix program since 2000. This program, which involves fitting a 3 star showerhead, tap regulators and a cistern displacement device, repairing minor leaks and providing water efficiency advice, saves on average 21 kL/household/annum (Turner et al. 2005). This program alone therefore currently saves over 8,200 ML/a of water (Sydney Water Corporation 2008). Similarly in Sydney the washing machine rebate provided by SWC on 4 star machines has introduced over 117,000 additional efficient washing machines into Sydney, providing a saving of 2,430 ML/a (Sydney Water Corporation 2008).

Whilst greywater and small-scale wastewater treatment systems are currently relatively uncommon at the household scale, despite rebates being available, rainwater tanks are becoming very common. For rainwater tanks a combination of rebates for existing properties and regulations for new and refurbished properties is beginning to create a significant shift in the number of rainwater tanks within urban areas across Australia.

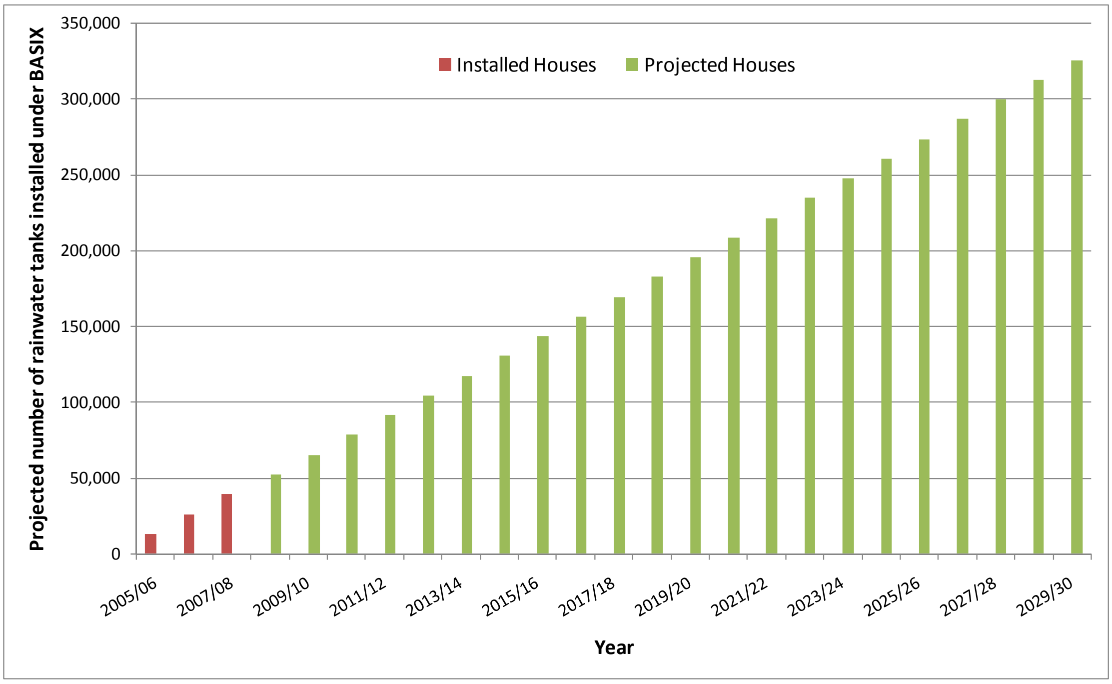
For example, in NSW the Building Sustainability Index (BASIX) regulations which have gradually been implemented across the state since July 2004 require that all new houses (and existing houses being refurbished) reduce mains water consumption by between 0 and 40% (depending on the location) when compared to average household consumption[1].

Due to the BASIX regulations alone, 290 ML of rainwater tank storage was fitted to new houses between 2004 and 2008 in NSW. This represents a significant increase in the number of small-scale supply systems. Over 90% of the tanks fitted are used to supply indoor end uses (Department of Planning (NSW) 2008a), which often necessitates the need for small pumps to pressurise the supply and small disinfection units such as UV-based devices to provide additional pathogenic protection.

[1] http://www.basix.nsw.gov.au/information/about.jsp [accessed 01/12/08]

Hence, in the last 3 years approximately 13,000 rainwater tanks have been installed annually in newly built single detached dwellings in NSW due to BASIX. Based on this rate of uptake, by 2029/30 there will be over 320,000 rainwater systems in NSW due to the BASIX program alone. This projection is illustrated in Figure 2.3.

Figure 2-3 Potential number of rainwater tanks in BASIX houses in NSW due to BASIX program alone



At a national level, in January 2009, the federal Department of Environment, Water, Heritage and the Arts (DEWHA) announced $250 million in funding for rainwater tank rebates for existing households across Australia, with rebates of up to $500 per household available for those that install a tank with internal plumbing (DEWHA 2009).

In Sydney, rainwater tank rebates of up to $1,500 are available for existing households installing rainwater supply for indoor end uses and to date approximately 47,000 rainwater tank rebates have been handed out to householders in Sydney (Sydney Water Corporation 2008).

There has also been a significant shift in the number of rainwater tanks in existing households not affected by BASIX regulations (i.e. those not within NSW and those in NSW not undergoing major renovation), due to other various state and local government rebate programs available. In these existing households there is a lower propensity to connect to indoor end uses such as toilets and washing machines due to the difficulties and expense associated with reconfiguring existing plumbing and guttering. Hence most of these rainwater tanks are connected to outdoor end uses such as garden water alone which also means there is likely to be less need for individual pumps and UV disinfection systems.

2.3 A POTENTIAL PROBLEM

Whilst the intent of the large-scale desalination plants and reuse schemes is to provide additional and more diverse supply-side sources, they predominantly increase the energy intensity and greenhouse gas (GHG) impacts of our urban water systems (Kenway et al. 2008). Similarly, water efficiency and source substitution options aim to save water, however little evaluation of actual water savings being achieved is undertaken and in the few rainwater tank programs evaluated they appear to be providing significantly lower savings than their full potential (Snelling et al. 2006; Turner 2007).

In addition the consequences of these initiatives on energy usage have at best been given a cursory assessment. In the case of showerheads, theory and research indicate there is a significant reduction in energy associated with a reduction in hot water use (see Flower et al. 2007). In the case of rainwater tanks very little is publicly available on the actual energy implications of rainwater tanks except for a study of the Silva Park development at Payne Road which indicates very high energy usage (Beal et al. 2008; Gardner et al. 2006) (refer to Chapter 3 for details).

We are currently at a critical juncture, where the diverse portfolio of supply and demand-side options currently being invested in requires significant investigation in terms of water savings/yield, energy usage, GHG implications and economic, social and environmental costs and benefits.

If the full potential of water efficiency and the use of source substitution in distributed systems are to be harnessed it is critical that water service providers and resource managers are fully aware of the interdependencies between water and energy in their region. This applies both to major infrastructure such as dams and desalination plants and to smaller distributed systems using efficient appliances and source substitution. Such information will enable them to make more informed policy decisions which take into account the trade-offs between water and energy use from a systems perspective.

This will help to minimise the risk of inadvertently increasing energy usage due to misinformed installation of technologies or ongoing sub-optimal management practices. It will also enable comparison between different water efficiency and source substitution systems in terms of water savings, energy usage, GHG implications and economics compared to major supply systems such as dams, desalination plants and reuse schemes.

The following chapters bring together the limited literature and investigations on the energy intensity of both large and small-scale systems to assist in filling some of these knowledge gaps.

3 OVERVIEW OF ENERGY USE IN THE WATER SECTOR

Various studies investigating the water-energy nexus are highlighted in the literature review which complements this report. This review reveals that several large studies have been undertaken that have examined the energy intensity of large-scale centralised treatment and distribution systems, both in Australia and the United States. However, few studies have examined the energy implications of smaller, decentralised systems. This chapter broadly summarises previous investigations into the energy intensity of water systems.

3.1 CONVENTIONAL LARGE-SCALE SYSTEMS

The energy intensity of large-scale centralised water treatment and distribution systems varies widely from city to city, depending on the location of the raw water source, treatment type, topography and the method of wastewater disposal. The Pacific Institute's study (Cohen et al. 2004) of energy intensity in Californian water systems found the following average intensities for each step in the urban water cycle.

Table 3-1 Average energy intensities of steps in the Californian water cycle (Cohen et al. 2004)

Step in water cycle	Average energy intensity (kWh/kL)
Raw water treatment	**0.56**
Local distribution	**0.21 (up to 1.16 depending on location)**
Wastewater treatment	
- Trickling filter	**0.28 – 0.72**
- Activated sludge	**0.42 – 0.92**
- Advanced treatment	**0.49 – 1.07**
Water transfer from San Francisco to Southern California	**2.43**
Water transferred from the Colorado River to Southern California	**1.62**

In Australia, Kenway and others have conducted a series of investigations into the energy intensity of water systems in major Australian cities. Kenway's findings (Kenway et al. 2008) have been summarised in Table 3-2. The energy intensity of water supplies in Adelaide, Sydney and Perth is currently considerably higher than for water supplies in Melbourne or the Gold Coast.

Table 3-2 Summary of energy intensities associated with water treatment, supply and wastewater disposal in cities around Australia during 2006/07 (Kenway et al. 2008)

	Sydney	Melbourne	Brisbane	Gold Coast	Perth	Adelaide
Water supplied (kWh/kL)	1.03	0.09	0.68	0.21	0.98	1.84
Wastewater (kWh/kL)	0.47	1.13	0.57	1.00	0.71	0.69
Total excluding end use (hot water) (kWh/kL)	1.49	1.22	1.25	1.21	1.70	2.52

Water passing through Adelaide's water supply and disposal system had the highest overall energy intensity at 2.5 kWh/kL, excluding the energy used to heat water at the point of use. This is significantly higher than the energy intensity for all other Australian cities and is approaching the high energy intensity of water passing through the urban system in Southern California.

The energy intensity of these centralised water systems has in some locations already been affected by the emergence of new centralised infrastructure that has been used to augment the existing systems. In other cases new infrastructure (predominantly desalination and reuse schemes) is about to be connected which is likely to further increase the energy intensity of the water services being provided.

3.2 NEW LARGE-SCALE SYSTEMS

The impact of centralised augmentation on existing water systems can be seen by examining the change in energy intensity of water supplied to Sydney, Perth and Adelaide. Table 3-3 shows how the energy intensity of water supply has changed in recent years. In Sydney, pumping from the Shoalhaven River has quadrupled the energy intensity of Sydney's water supply. In Perth, the 45,000 ML/a desalination plant located at Kwinana became operational in November 2006. The energy intensity of Perth's water supply almost doubled over five years, primarily due to this plant. In Adelaide, energy intensity also doubled from one year to the next, as drought conditions prompted large-scale water pumping from the Murray River. While some of these measures, such as pumping from the Shoalhaven or the Murray have been introduced as temporary drought measures, it is a concern that these arrangements may become more permanent if drought conditions do not abate significantly. In addition, in all three locations desalination plants are planned or about to be connected to the system thereby further increasing the energy intensity beyond those currently observed in 2006/07 figures.

Table 3-3 Energy intensity of water supply before and after large-scale system augmentation in Sydney, Perth and Adelaide (Kenway et al, 2008)

	Sydney		Perth		Adelaide	
Year	2000/01	2006/07	2001/02	2006/07	2005/06	2006/07
Energy intensity (kWh/kL)	0.25	1.03	0.56	0.98	0.85	1.84
Comments		Pumping from the Shoalhaven		Desalination		Pumping from the Murray

3.3 HOT WATER USAGE AND WATER EFFICIENCY

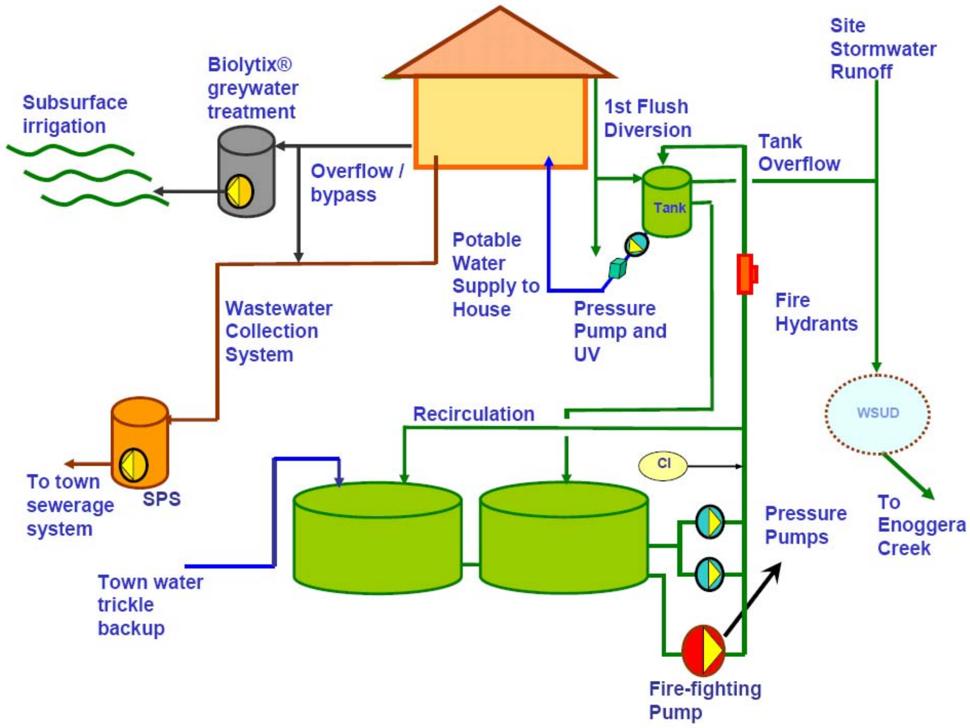
While the energy intensity of these existing and emerging large-scale systems is high, the energy used to treat and transport water is significantly less than the energy used to heat water in the home. The energy used to heat water from 18°C to 60°C, calculated from first principles is 47 kWh/kL. This figure brings to light the significance of water efficiency when it comes to the heating and use of hot water. Efficient use of hot water will not only reduce the energy used to heat water at the point of use, but will also have upstream and downstream impacts, by reducing the volume of water that needs to be treated and transported.

3.4 EMERGING DECENTRALISED SYSTEMS

As indicated in Chapter 2 there is little literature on the actual energy usage of decentralised systems associated with greywater and rainwater tanks. The most recent study of energy related to rainwater tanks investigates the Silva Park development at Payne Road, the Gap, Brisbane. The development has several WSUD elements as illustrated in

Figure 3-1 below.

Figure 3-1 Silva Park Schematic from Beal et al. 2008



The study reports on energy and water associated with rainwater supply and greywater re-use systems for the six occupied homes. The characteristics of the rainwater systems are summarised in Table 3-4 (Beal et al. 2008; Gardner et al. 2006).

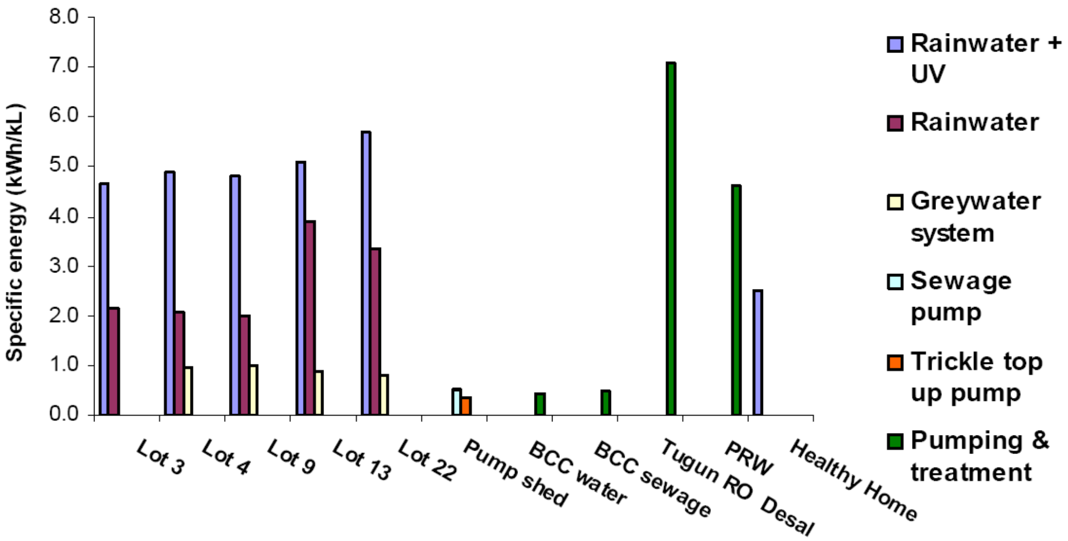
Table 3-4 Characteristics of the rainwater system at Silva Park

	Rainwater tank volume	Backup supply	Pump	Other information
Individual houses	18-22 kL nominal	Top-up from communal tanks (float valve triggered when level at 20%)	Submersible pump 0.45 kW	40 W UV disinfection unit – all water
Communal Supply	75 kL x 2	Mains top-up	0.75 kW for household top-up, and “matching pump to recirculate water through the communal tanks” (Diaper et al. 2007, p. 51)	Auto start when pressure drops below 350 kPa
			22 kW diesel pump for fire fighting supply	

Energy measurements for the pumps at communal and household levels were made at ten-minute intervals.

The energy intensity of rainwater supply (together with other energy-using water services) to each individual lot is shown in Figure 3-2 below, reproduced from Beal et al. 2008. The figure suggests an average energy intensity for rainwater pumping of around 3 kWh/kL. The energy intensity of the rainwater system *including UV treatment* is reported as a very high 5 kWh/kL.

Figure 3-2 Energy intensity of water system components at Silva Park (Beal et al 2008)



The authors (Beal et al. 2008) attribute the high energy intensity of the water supply at the site to:

- the topographical features of the site and development, i.e. communal "rainwater tanks located at the bottom of the subdivision" and "high pumping heads (e.g. Lot 22 is a 3 storey structure)";
- the "intrinsic inefficiencies in the delivery system design as the submersible pumps start at even a small pressure drop in the household plumbing"; and

"multiple start ups [of on-lot pumps] per hour which draw a higher current than during normal pumping operations." The current study notes that the subdivision was designed specifically to be water efficient, and energy appears not to have been a major consideration at the design stage. This has resulted in a 'cascade' system for backup supply which is particularly inefficient from an energy perspective, where water from communal tanks is pumped to top-up on-lot tanks and then pumped again to supply end-uses in the dwellings.

The authors of this research project suggest that the high energy intensity of the rainwater system summarised in Figure 3-2 is due to the repeated pumping of water as noted above. This hypothesis was tested against an indicator for the amount of on-lot tank top-up, namely, the total water used by a house relative to the size of its on-lot tank. The logic of this approach is that the more water consumed, the more likely the on-lot tank required topping up with communal tank water – hence more water has been pumped twice, leading to a higher energy intensity.

The last column in Table 3-5 below shows the indicator of topping up in a re-analysis of data presented in Beal et al. 2008. It shows that Lot 13 would require the most topping up, followed by Lot 22, with Lots 3, 4 and 9 having similar levels of top-up. These relative ratios correlate well with Beal et al.'s graph of energy intensities for rainwater use for each lot shown in Figure 3-2.

Table 3-5 Ratio of on-lot tank volumes to total water use

Lot number	Total water use (kL/hh/year)	Active tank volume (kL)	Ratio (Total water use / active tank volume)
3	143	14	10
4	139	14	10
9	132	12	11
10	85	14	6
13	344	14	25
22	142	10	14

Beal et al.'s proposition that power surges of a few seconds' duration at pump start-ups are a significant contributor to energy intensity, warrants further investigation. Beal et al.'s monitoring configuration, which averages energy consumption of the pumps over 10-minute intervals, was too broad to directly verify the impacts of start-up, but it appears that they have conducted tests that suggest "no statistical relationship between specific energy use and number of pump 'start ups' per kL", thereby contradicting this proposition. One of the aims of this research project is to investigate this issue.

It is important to note that the rainwater system at Silva Park is not a typical configuration as the majority of Australian rainwater tanks have been fitted to a single lot and do not have a separate system where overflow is stored and used for top-up. Hence an additional focus of this research project is to identify "typical" or "common" systems and to determine whether these systems show similarly high energy intensity. This will help identify the characteristics that contribute to high energy consumption.

4 STUDY SCOPE

When this research project commenced, the intent was to use data from existing case studies to compare theoretical energy intensity of water saving initiatives such as rainwater tanks and greywater systems with actual energy intensity. However, as the project progressed a number of issues arose which contributed to a change in scope. One of these issues is a significant gap in the availability of existing data.

4.1 DATA AVAILABILITY

In the preliminary literature review five potential houses/developments were identified where energy reduction and water savings were explicit design objectives. These sites were targeted as potential case studies, where it was thought that it might be possible to gather data on water consumption and corresponding energy use. However, after contacting the relevant people involved in operating and/or monitoring these sites, it became evident that while in some cases monitoring of water consumption was being undertaken, there was no corresponding energy data available. In Table 4-1 below, the original case study information has been set out along with the outcomes of enquiries into monitoring data.

Silva Park / Payne Road is the only site where water use and corresponding energy data has been collected and studied. At this stage the only other site that is undergoing the process of monitoring is Currumbin Ecovillage. This site is now the subject of an intensive monitoring study in which *Ecovision* energy and water meters are installed as each new house is built. The meters are monitoring electricity consumption (rainwater pumping, general power, lighting, photovoltaic power generation) and gas and water consumption (potable water from rainwater tanks, recycled water, hot water) at five-second intervals. The data for Currumbin Ecovillage is already committed to another research project (Callaghan 2008) and is therefore not available for this study.

4.2 REVISED SCOPE

Due to the lack of energy monitoring data available for new water infrastructure at the lot and estate scales it was decided that primary data collection would be highly beneficial. Studies by Beal et al. (2008) and Gardner et al. (2006) which examined the energy intensity of the rainwater system at Silva Park / Payne Road found unexpectedly high values. However, the configuration of individual rainwater tanks supplemented by an estate scale top-up system is relatively unusual and this type of system is not representative of the majority of household rainwater systems around Australia.

Table 4-1 Original list of potential case studies for evaluation of energy related to emergent water service infrastructures

Water service	Case study	Scale	Characteristics	Technology	Energy implications	Energy data potential	Outcome of Inquiries
Co-treated grey water and stormwater	Inkerman D'Lux, Melbourne VIC (Clearwater 2005; Melbourne Water undated)	Mixed Greenfield development – 245 dwellings (medium-high density apartments) and retail Communal scale greywater system	Treats greywater from 50% of the dwellings, along with rainwater and stormwater. Re-use in toilet flushing and garden irrigation	Membrane Bioreactor (MBR) tanks, an aeration balance tank and a sand/soil/gravel wetland, UV disinfecting unit	For water utility: Anticipated potable water savings of 20% and 40% in winter and summer respectively. Reduced discharge to sewer. For strata manager: Energy associated with treatment and pumping	Dwellings designed for energy efficiency. Non-potable water system design aim to keep low maintenance and energy costs.	Discussions were held with the South East Water representative operating the plant, however energy consumption specifically related to the greywater system has not been monitored separately and cannot be disaggregated from the general electricity consumption information available.
Rainwater for potable supply	599 Payne Road Brisbane QLD (Diaper et al. 2006; Naiad 2007b)	Greenfield residential development, low density – 22 allotments, not complete Lot-scale rain tanks and greywater system Communal raintanks for backup supply to household tanks. Trickle feed backup from mains water.	Treated rainwater for all indoor uses	carbon filtration and UV disinfection	For water utility: No supply or sewage services – Development is designed to be self-sufficient for water services. For strata manager: Energy associated with treatment and pumping	Extensive monitoring of water and water-related energy has been designed into the project.	Useable data exists in literature (Gardner et al. 2006). Unexpectedly high energy related to pumping is reviewed in Chapter 3 of this report.
Onsite greywater treatment			On-site greywater treatment with kitchen waste Re-use in subsurface irrigation	Biolytix aerobic vermiculture system Soil moisture sensor to control flows, overflow to sewer.			
Rainwater, onsite greywater treatment in cascade	Clovelly House Sydney NSW (Veale 2006)	Single residence, infill	Rainwater to showers and handbasins Treatment of grey water from showers and handbasins, re-use in laundry and toilet.	First known use of "green wall" treatment system – a set of plant boxes with filtrate that treat and polish grey water to high quality. UV disinfection	For water utility: 80% reduction in potable water, and reduction in sewer discharge. For homeowner: Small pumps for circulating rainwater, untreated and treated greywater from holding tanks, and UV disinfection systems add energy	Sustainability including water and energy efficiency were design objectives for the renovation.	No response to repeated communications to the architect through whom we were advised to contact the owner. According to ISF's Caitlin McGee who has written a case study on this house, the architects had on a previous occasion noted owner fatigue with external interest in their home and were seeking to limit intrusion on

Water service	Case study	Scale	Characteristics	Technology	Energy implications	Energy data potential	Outcome of Inquiries
					consumed by household. Net energy impact not known.		them.
Alternative sewerage system	Pimpama Coomera Gold Coast QLD (Apostolidis 2003; Diaper et al. 2006; Mitchell 2006; Naiad 2007a)	Greenfield subdivision with ultimate population of 150,000 by 2056. Low density housing, with some commercial and industrial sites.	"Smart sewers" transport wastewater for centralised wastewater treatment (and third pipe reticulation for irrigation) Coupled with rain tanks for indoor non-potable use, providing water cascade.	Reduced infiltration gravity sewer network Some pressure sewers and vacuum sewers were more suitable.	For water utility: Anticipated potable water savings up to 84%. Reduced volumes of sewage from low infiltration. Costs related to third pipe. For homeowners: small pumps for rainwater add to energy consumption. Pressure/vacuum sewers energy – allocated to utility? Strata? Homeowner?	System monitoring is designed into the project	Monitoring of recycled water consumption will commence in mid 2009, when the recycled water supply comes online. This unfortunately is beyond the timeline of this study. There are no plans to monitor rainwater use or energy specifically at this site.
Wastewater treatment including alternative sewerage	Currumbin Eco-village Gold Coast (Diaper et al. 2006)	Greenfield low density development for 144 houses, commercial and communal facilities.	Innoflo system for communal wastewater treatment and non-potable reuse Coupled with rain tanks and high level efficiency,	Water-tight onsite interceptor tanks with effluent filter, watertight small bore sewers, treatment pod with engineered textile media bioreactor, UV disinfection	For water utility: no water supply or sewerage service. The village is designed for total self sufficiency in water services (water and wastewater) Energy related to alternative technologies	Ongoing monitoring post implementation is built into project design	*Ecovision* energy and water meters were installed in July 08, monitoring electricity (rainwater pumping, general power and lighting, photovoltaic power generation), gas and water consumption (potable water from rain tanks, recycled water, hot water). This site is the subject of another study and data is not presently available.

As the only available data represented an unusual rainwater harvesting system, it was decided that more "typical" household rainwater systems should be monitored to determine a more representative value for energy intensity of common household rainwater systems.

Consequently, it was decided to monitor a number of rainwater systems at the lot scale in order to obtain some empirical data on the energy consumption of rainwater systems and to gain more information on how the energy intensity is affected by different system components. The range of components available for rainwater systems has been summarised in Chapter 5. Part of the process of identifying system components involved determining which type of rainwater system represented a "typical" configuration. The characteristics of common and less common rainwater systems is also discussed in Chapter 5.

The monitoring component of this research project has been limited to a small sample of rainwater systems at the single lot scale due to time and budget constraints. Whilst the sample size and the focus on a single lots is not ideal, this research represents the first detailed assessment of the water and energy usage of multiple rainwater tank configuration publicly available and aims to unveil the energy intensity of "typical" systems. Further research is needed on both single lot level and the more complex estate scale systems. This gap in knowledge may in part be filled by SWC, which (at the time of writing this report) is in the process of monitoring and evaluation of water and energy of a sample of BASIX households in Sydney. The results of the research are expected in early 2009/10 (pers comm Jessica Sullivan, 2009).

In preparation for the monitoring exercise undertaken for this research project a theoretical rainwater system energy consumption model has been developed to examine the difference between theoretical and actual pump energy usage. The theoretical model is explained in Chapter 6 and the modelling results are discussed in Chapter 7.

The intent of this research project is to examine and identify the design and implementation issues associated with emerging water infrastructure that may result in water delivery with high energy intensity. This research project has narrowed its focus to rainwater systems, due to the paucity of available data and the need for primary data collection. However, more investigation into other household- and estate-scale systems is required in order to ascertain the overall energy implications of changes to the urban water cycle. By unveiling the potential issues that impact upon energy consumption, the industry can move towards solving them as part of the policy, design, implementation and ongoing usage chain.

5 RAINWATER TANK SYSTEMS

The study conducted at Payne Road demonstrates that certain rainwater systems have a very high energy intensity. Hence as part of this research project, it has been necessary to identify which types of rainwater systems are more common so that it is possible to make a more general assessment about the energy intensity of household rainwater systems. Whilst the number contacted was not extensive, some stakeholders in the rainwater tank industry assisted in developing this picture.

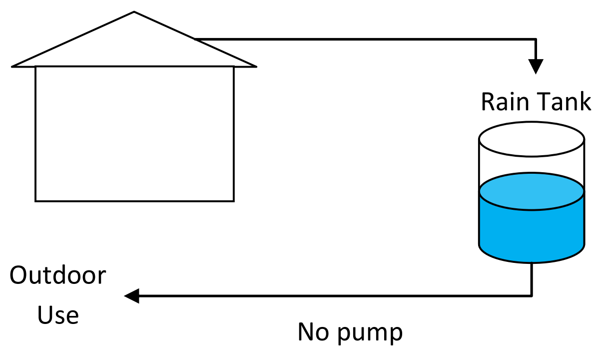
After obtaining a picture of what can be termed “typical”, individual elements have been considered in greater detail to determine their potential role in increasing energy intensity and how system configurations can be improved to reduce energy intensity and overall energy consumption.

5.1 TYPICAL CONFIGURATIONS

Discussions with plumbers and others involved in installing rainwater tanks have indicated that typical rainwater harvesting configurations involve the connection of rainwater tanks to toilets and outdoor uses. This general assessment of typical rainwater connections is consistent with the latest BASIX assessment which states that 98% of alternative water connections in 2007/08 were for garden use, followed by toilet flushing (91%) and laundry use (82%). Ninety-five percent of these houses were using rainwater as their alternative water source (Department of Planning (NSW) 2008b). Most urban installations also use a switch to mains such as the Davey rainbank or Onga water switch (Caley, J. Green, A, pers. comm. 2008). However, many studies note the use of trickle top-up systems (Coombes 2002; Coombes et al. 2003). The differences between those systems using a mains switch and those using a trickle top-up system are illustrated in Figure 5-2 and Figure 5-3 respectively.

When rainwater tanks became more popular at the onset of the most recent droughts, the first household rainwater systems were relatively simple in that they collected rainwater for outdoor uses such as irrigation and car washing and used a tap and bucket or a gravity-fed hose to deliver the rainwater. Many such systems exist in urban Australia and do not pose any issues in terms of energy, as they do not use pumps. This type of simple configuration is illustrated in Figure 5-1.

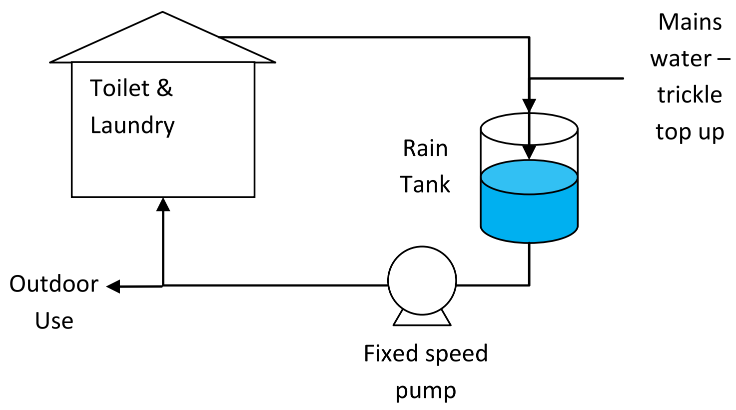
Figure 5-1 Schematic of a simple household rainwater system for outdoor use



However, if these systems are retrofitted with pumps to achieve greater utility of the rainwater available, the type of pump and configuration will become more important.

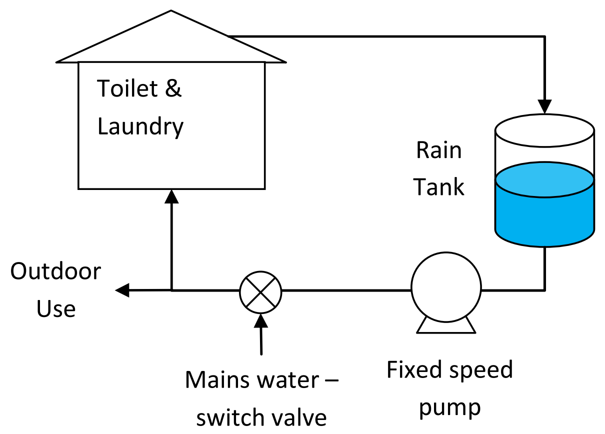
As the droughts around Australia continued, rainwater was increasingly used for a greater number of end uses such as toilet flushing and the laundry. These indoor end uses require not only a pump to ensure pressure, but also a reliable backup from the mains supply. Initially trickle top-up systems were used as a means of supplementing rainwater supply and as a means of preventing backflow into the mains water network (Coombes 2002; Coombes et al. 2003).

Figure 5-2 Common rainwater system configuration using a trickle top up



However, trickle top-up systems are less than ideal as they depressurise the mains supply, which then requires re-pressurising via the household pump. Additionally, the owner of a rainwater system with trickle top-up is less likely to be aware of when rainwater is running low and when the system is essentially only using mains water. A schematic of a trickle top-up system is shown in Figure 5-2 above. The mains switch has recently been developed and this is now a more common method of providing mains water backup. This is illustrated in Figure 5-3 below.

Figure 5-3 Common rainwater system configuration using a mains switch



The possible variations in system components are summarised in Table 5-1. The range of potential combinations means that household rainwater systems vary considerably. However, due to customer feedback and the business acumen of the rainwater tank and pump manufacturing industry it is now common to buy complete rainwater harvesting systems and/or controls.

Table 5-1 Range of rainwater system components

Storage	Pump	Mains backup	Pressure assist
• **Tank**	• Fixed speed (external and submersible	• Trickle top-up	• Header tank
• **Bladder**	• Variable speed	• Mains switch	• Pressure vessel
• **Storage wall**	• Venturi	• Other valves (e.g. solenoid)	• Gutter storage

The size of rainwater storages varies depending on space, location, roof catchment area and rainwater demand. Statistics from the BASIX program indicate that the most common tank size range installed (32% of new houses in Sydney) was 2–3 kL. The second-most common tank size range was 4–5 kL, installed in 22% of new houses (Department of Planning (NSW) 2008b).

The system elements and configurations are discussed in more detail in the next chapter.

5.2 SYSTEM ELEMENTS – POTENTIAL ISSUES AND SOLUTIONS

As discussed in the previous chapter, rainwater systems have become more complex over time with additional components to improve pressure or provide a reliable mains backup supply becoming more common. The function of each system element is explained here along with potential issues that may contribute to increasing energy and water consumption. Potential solutions have also been provided as suggestions for system improvement. In some cases these solutions need to be verified through further investigation.

5.2.1 STORAGE

Rainwater can be stored in the traditional cylindrical tanks (above or below ground) or in more modern storage units that have been designed to fit more readily into existing urban areas such as plastic storage walls, gutter storages and bladders placed beneath houses.

Figure 5-4 Example of a domestic rainwater storage tank

Potential Issues: The main issue for energy consumption is not the type of water storage, but where that storage is placed relative to the end uses. In rainwater systems where storages are placed underground or at the bottom of a hill below a house, the lift required by the pump to deliver water to the end uses is much greater. Hence more energy is consumed in delivering rainwater than would be the case for an upright storage standing at the same level as the house.

Potential Solutions: If storages are placed as high as possible relative to the end uses, gravitational energy can be used to assist water delivery. Systems such as gutter storages – wide and deep gutters that sit on a building's perimeter wall – make best use of gravity. New designs incorporating characteristics for systems such as those in the UK, where in some cases a header tank in the eaves of the house is used, could also be of benefit. However, the head required for specific end uses such as washing machines needs to be considered.

5.2.2 PUMP

The demand for rainwater and the storage characteristics of a system determine the size of the pump required. A rainwater system with a larger number of end uses and an underground storage tank will necessitate a more powerful pump than a system that is supplying rainwater for a single end use where the pump and storage are placed at ground level.

Figure 5-5 Example of a domestic rainwater pump

In household rainwater systems, fixed speed pumps are most commonly used. These pumps draw approximately the same power regardless of the volume of water that is being delivered, which means that the same amount of energy is being used to deliver water to a single tap as would be used to deliver water to the tap and two showers running simultaneously[2]. In addition, fixed speed pumps are designed to operate at a "best efficiency point" or BEP which is a specific head and flow rate. These pumps are most efficient when the household system matches these intended design characteristics. As all household configurations are different, many household pumps are likely to be operating at less than optimal efficiency.

Variable speed pumps use pressure sensors to detect the power required to pump water, so that the pump operates at a lower speed when a single tap is open and speeds up when several taps are switched on. This type of pump can be useful for applications where the load profile is highly variable, such as in a household that uses rainwater to supply small end uses such as hand basin taps as well as large end uses such as showers and clothes washers. A variable speed pump in this situation will keep the water pressure more consistent and may operate more efficiently as the pump speed adjusts according to the demand from various end uses.

There are many different types of pumps that can be selected for use in a rainwater system, however care must be exercised when a non-standard pump is used. In this research project, a venturi jet-assisted pump common for well applications was used in a rainwater system. A venturi pump can be an appropriate pump when pumping is required to draw from very deep water reservoirs, however it is not a suitable choice for an efficient rainwater system. A venturi pump uses extra energy to create suction needed only in deep applications.

Potential Issues: It is important that pumps be designed for their application to achieve high energy efficiency.

[2] Initial tests run by ISF indicate that a small pump typical of a rainwater system will have approximately constant power usage when pumping regardless of flow. Information obtained from Davey Pumps predicts a 10–30% variability in the power required between a high flow end use and a low flow end use, although energy usage is highly dependent on the pump selected and may actually increase at low flows.

Potential Solutions: For optimal energy efficiency, a pump needs to be matched to the system for which it is selected. For rainwater applications this is most easily achieved by using a pump designed for a rainwater (or similar) system. Further, the pump should be selected such that it matches closely all end uses attached to the rainwater system.

5.2.3 MAINS WATER BACKUP

Trickle top-up systems

This method of mains water backup operates via the use of a float level sensor that detects when the water level is low in the tank. Once the float reaches a certain threshold, the top-up system is triggered and a trickling tap is opened. This trickle fills the tank slowly until an upper threshold is reached and the valve is shut. This means that the mains water backup is routed through the tank and mixes with rainwater, which also means that the rainwater system's pump is always operating, even when only mains water is being used.[3]

Potential Issues: Filling a rainwater tank with mains water means that the pressure supplying the mains water is lost or "broken", causing a loss of energy. This water then needs to be re-pressurised through the use of a pump, using more energy than would be required to pump rainwater alone. This issue is more pronounced in systems where the rainwater storage is small and top-up is required frequently.

Apart from using energy unnecessarily, a trickle top-up system can be somewhat deceptive to the householder, as the rainwater tank is never empty and the householder may not be aware that they are using mains water instead of rainwater.

Potential Solutions: Top-up can be minimised when rainwater yield (related to available storage) is adequately matched to end uses. If demand is always greater than the available supply, then top-up will be required regularly and the rainwater tank pump will operate even though no rainwater is being used. Extra storage and or increased catchment area from the roof may reduce the need for mains water top-up.

Another alternative is to use a mains switch system. This type of system is explained under the following sub-heading.

Mains switching system

There are two mains switching systems commonly used in Australian households. These are the Davey Rainbank and the Onga Water Switch. These switching devices are placed after the rainwater systems' pump and use a float level sensor to detect when rainwater is in short supply. When rainwater is low, the device opens a valve to supply mains water to the end uses that normally use rainwater. As a backup supply system, this option is more energy efficient than the trickle top-up system because the mains supply retains its pressure and does not need to be re-pumped. These switching devices are matched to particular pumps as they also control the pumps' on-off cycling. Unlike other pump controls, these switching devices do not allow pump run-on, so the pump switches off immediately after taps are turned off at the point of use. One disadvantage with this system is that

[3] In the less common configuration where rainwater provides water for all household end uses, there could be benefit in using a trickle top-up system to avoid stagnation of water in the tank when the level is low (which could affect water quality and is important when rainwater is used for potable end uses)

when a tap is opened again, there is insufficient pressure in the line to deliver water immediately. This is remedied by the switching device which uses a small volume of mains water at the beginning of each water use event to boost pressure while the pump is starting up. However, this remedy uses mains water which the rainwater tank system aims to save. This system represents a trade-off between water and energy consumption; the switching device is more energy efficient as it utilises mains pressure, but it uses more mains water in the process.

Figure 5-6 Example of an automatic switching system commonly used for domestic applications

Potential Issues: This backup system does not present any specific issues in terms of energy consumption, apart from standby power which may or may not be significant (requires further research). As the volume of mains water used in general operation is unknown, this could potentially represent an issue in terms of water consumption.

Potential Solutions: Such issues would be mitigated through the improved design of switching devices.

5.2.4 PLUMBING

Piping, taps and connections are required to deliver rainwater from the roof to the storage and then to the end use. As in any water system these connections need to be maintained to ensure there are no leaks. Recent research in Hervey Bay has found from a pilot study that 2% of meters accounted for 24% of consumption during minimum night flows with almost half the leaks being associated with toilets (Britton et al. 2008). This indicates that although only 2% of households may have discernable leaks the volumes of water can be significant and if located in households with a rainwater tank could significantly impact on the rainwater tank yield, mains water usage and energy usage (i.e. pumps running virtually continuously on trickle top-up systems).

Piping should be sized to match the rainwater system. Larger pipes will lower system resistance which can reduce energy consumption; however pressure and flow need to be maintained at the point of use.

Potential Issues: Leaks can cause significant losses in both water and energy as they can cause frequent cycling of the pump or continuous operation. Slow opening valves on some appliances such as toilets can result in prolonged pump operation and for fixed speed pumps mean they operate at a sub-optimal level.

Potential Solutions: Plumbing must be maintained and leaks need to be fixed as they occur in order to minimise water and energy losses. Higher quality appliances, such as toilets that can withstand higher flow rates, fill more quickly and use less water, will mitigate the energy consumed by older style slow trickling toilet cisterns.

5.2.5 RAINWATER TREATMENT

Water treatment in rainwater systems varies according to the specific end use. Rainwater used outdoors typically only has a simple screen to prevent debris from entering the tank. First flush systems which discard an initial volume of runoff are also commonly used to improve rainwater quality. Rainwater system filters tend not to use any energy but could cause head losses if accidentally placed after the pump in a rainwater system. Treatments required for drinking rainwater such as UV lamps also use energy.

Potential Issues: Small-scale treatment systems may use proportionally more energy than large-scale water treatment systems. Poorly designed or placed filters could result in unnecessary head loss in a rainwater system.

Potential Solutions: Filters should be placed on the inlet to a rainwater tank or before the pump as particles in the rainwater can cause pumps and switching devices to malfunction. The energy consumption of small rainwater treatment systems needs further investigation.

5.2.6 PRESSURE ASSISTANCE

Pressure in rainwater systems and the energy required to maintain pressure can be assisted through the use of pressure vessels or header tanks.

Pressure Vessels

A pressure vessel is a pressurised tank that is placed after the pump in a rainwater system. It holds a certain volume (typically 8, 20, 50 or 80 litres) of pressurised water and acts as a buffer between the varying demands from end uses and the pump cycling on and off. This means that water is drawn from the pressure vessel when a tap turns on and the pump only turns on when the pressure vessel is nearly empty. The pump will turn on when the outlet pressure drops below a threshold pressure and will stay on until the vessel is full and pressurised to a specified higher fixed pressure. The pump will only turn on again when the lower threshold is reached. This system allows the pump to operate closer to its best efficiency point and results in more efficient pump operation.

Pressure vessels are thought to provide more consistent water pressure to the end use, but this needs to be investigated as this is likely to depend on the design of the pressure vessel and the type of pump it is matched with.

One of the benefits of a pressure vessel is that it minimises the number of pump starts. Each time the pump turns on a short burst of extra power is required by the motor for a short period in order to start the pump. In some pumps this initial burst of energy is equivalent to approximately 30 seconds of normal pump operation4. By allowing the pump to run continuously while filling the pressure vessel, these pump starts are minimised and pressurised water is still available to the end use.

Figure 5-7 Example of a large domestic pressure vessel used as part of a rainwater supply system

The pressure vessel should however be matched to the selected pump and expected end uses in order to achieve optimal results.

Potential Issues: If a pressure vessel is placed in a system with a mains switching device, it is unlikely to function correctly as the switching device controls the pump's on-off cycling via a flow sensor. This means that when a tap is turned off and flow stops in the system, the pump will be switched off and the pressure vessel will not fill. In some cases, the addition of a pressure vessel to a system which uses a switching device may actually increase pump cycling. This was demonstrated in testing undertaken by Greg Bax at Apar pumps in Sydney (Bax 2008).

[4] Mark Lance, General Manager Engineering at Davey Pumps, states that 0.006 kWh is required by a standard pump that normally draws 0.74 kW. This is equivalent to 29 seconds of normal operation. (0.006kWh/0.74kW*(3600sec/1hr) = 29 sec)

A pressure vessel needs to be appropriately sized for the system. If the capacity is too small it is unlikely to reduce pump starts significantly. Additionally, if the difference between the high and low pressure thresholds that trigger pump operation is too great, the user may experience diminishing water pressure as the pressure vessel empties.

Potential Solutions: A pressure vessel should not be used in conjunction with a mains switching device as the switching device prevents pump run-on and pump run-on is required to fill the pressure vessel. An alternative would be to use a switching device that does not control the pump and is only triggered to supply mains water when the float valve in the tank detects low rainwater supplies.

The change in water pressure experienced by users as the pressure vessel is emptied needs to be investigated. Varying water pressure may not affect certain end uses such as outdoor use, washing machines and toilet flushing; however, it is undesirable for other end uses such as showers which are currently less commonly connected to rainwater systems.

Header Tanks

Header tanks are another option for reducing pump starts and ensuring consistent water pressure. A header tank is a small storage tank that is placed at an elevation greater than the end uses. Rainwater is pumped to the header tank until it is full and drains to the end uses by using gravitational energy. When the level in the header tank is low, the pump is triggered to start and run until the header tank is full. This ensures consistent and efficient operation of the pump.

Potential Issues: In suburban single-dwelling households it may be difficult to locate a header tank high enough to provide adequate pressure in the house for all end uses (e.g. most clothes washers require a minimum head to function satisfactorily).

Potential Solutions: Header tanks may not be appropriate in all locations, but may be useful in situations where it is possible to locate such a tank higher than the household or at least higher than ground-floor end uses. As previously indicated header tanks are used in several other countries around the world. The design of new houses in Australia could potentially be modified to incorporate some form of header and/or wall tank in future.

Following this overview of the various components that make up a rainwater system and associated potential issues and solutions, the next two chapters begin to investigate their theoretical and actual energy use.

6 THEORETICAL ANALYSIS

A major aim of this research project is to compare theoretical (modelled) energy intensity with actual (empirical) energy intensities of household rainwater supply systems. This task has been undertaken to help identify whether a large discrepancy in energy intensity exists between the modelled and actual energy intensities and if so, why. Four theoretical models were developed to estimate rainwater pump power usage. The four models were developed using different data sources for water usage and pump power. The data sources and assumptions behind the models are explained in this chapter. The results from these models are also compared.

6.1 WATER USAGE DATA

To create the theoretical pump models, household water usage data from small time-step metering by Yarra Valley Water (YVW) was used (Roberts 2004). This data, kindly provided by YVW, was collected using high-resolution water meters and data loggers with subsequent analysis using Aquacraft Trace Wizard© to determine specific end uses. Data from three houses in Melbourne was recorded during both winter and summer seasons. The data was recorded with a resolution of 0.01 litres and was sampled at 5-second intervals. None of the three houses chosen had rainwater tanks. The three houses have been used as representative cases of typical household water usage profiles. The data available was affected by restrictions and thus the outdoor component of water demand will be less than that of an average non-restricted year. However, the data is being used to determine the energy intensity of an average household through the use of various end uses throughout a typical week. Hence, the reduced outdoor component is likely to have only a small effect on the outcomes.

The datasets provided by YVW were disaggregated into water use events of a certain duration, so that the data was separated into events labelled as leaks, turning on a faucet, filling a toilet cistern, operating a clothes washer, irrigation, showers and baths. The modelling was carried out using this disaggregated data provided by YVW. The raw dataset was also viewed to determine if any discernable difference could be observed between the YWW disaggregated results and the original raw dataset. The disaggregated data predicted only slightly higher energy intensity compared to the raw data (approximately 3–4%). Results reported in this chapter are from the modelling undertaken using the disaggregated data.

6.2 PUMP MODELS

Four rainwater pumping models were developed to compare the results from a simple, constant-power pump model with models used for actual pumps provided by a major rainwater pump manufacturer. Water usage data from the three houses was used in separate runs of each pump model.

Initial model runs assumed that all end uses in each house were supplied by rainwater. In later runs the end uses supplied by rainwater were modified in order to compare the theoretically calculated values directly with data logged through actual monitoring. These results are explained in more detail in Chapter 8.

The model assumptions and the differences between the four pump models are explained in this chapter.

6.2.1 GENERAL MODEL ASSUMPTIONS

General assumptions adopted in theoretical modelling include the following:

- When an end use event occurs, such as when a toilet cistern refills or a tap is turned on, the flow and power are assumed to be the constant average throughout the event.
- Water use events identified in the data provided by YVW were assumed to be discrete events (i.e. not occurring simultaneously or overlapping)
- Peak power usage contributions due to pump start-ups drawing higher current than normal operation were not included in the model.
- Each pumping model assumes pump run-on is accounted for by the data sampling period; an end use is assumed to run for an entire 5-second sample if any water flows during its sample time, This assumption may slightly underestimate energy consumption as many pumps do continue to operate for a slightly longer time after flow has stopped. However, for some pumps the run-on period is negligible.

It is expected that all models will bias towards slightly higher energy intensities. A characteristic of the data is that there will be greater error if the data has significant short pump cycling with shorter duration than the sampling period. In this scenario, the pump will "run" for the entire sample period, even if a real pump would have only operated for a shorter period.

6.2.2 CONSTANT-POWER MODEL

It was observed in several sets of data that the pump power did not vary significantly across the range of typical flow rates. Therefore, a simplified model was developed that assumes a constant-power flow during pumping. This is a "worst-case" type model that should generate the highest energy intensity for a given power pump. However, the constant-power model is a reasonable approximation for a real single-speed pump, since the power variation due to flow will not be large. The constant-power model assumes that 750 watts will be used if water is flowing or no power if there is no flow. The power curve has been illustrated in Figure 6-1. Flow data has been applied to the model and a sample plot is shown in Figure 6-2.

Figure 6-1 Power Curve for the Constant-Power Pump Model

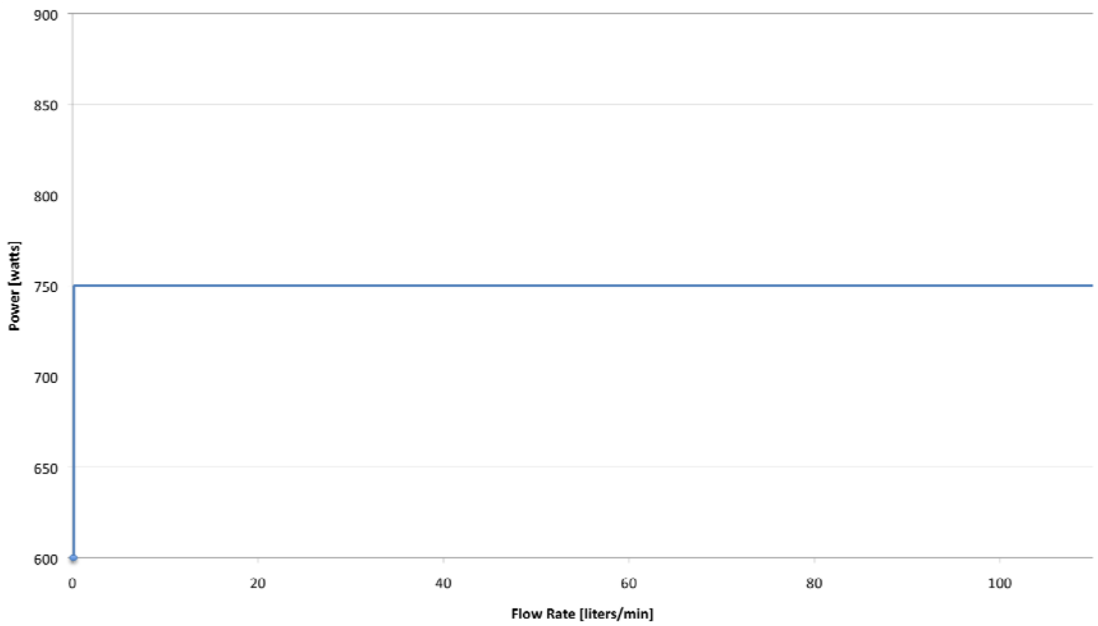
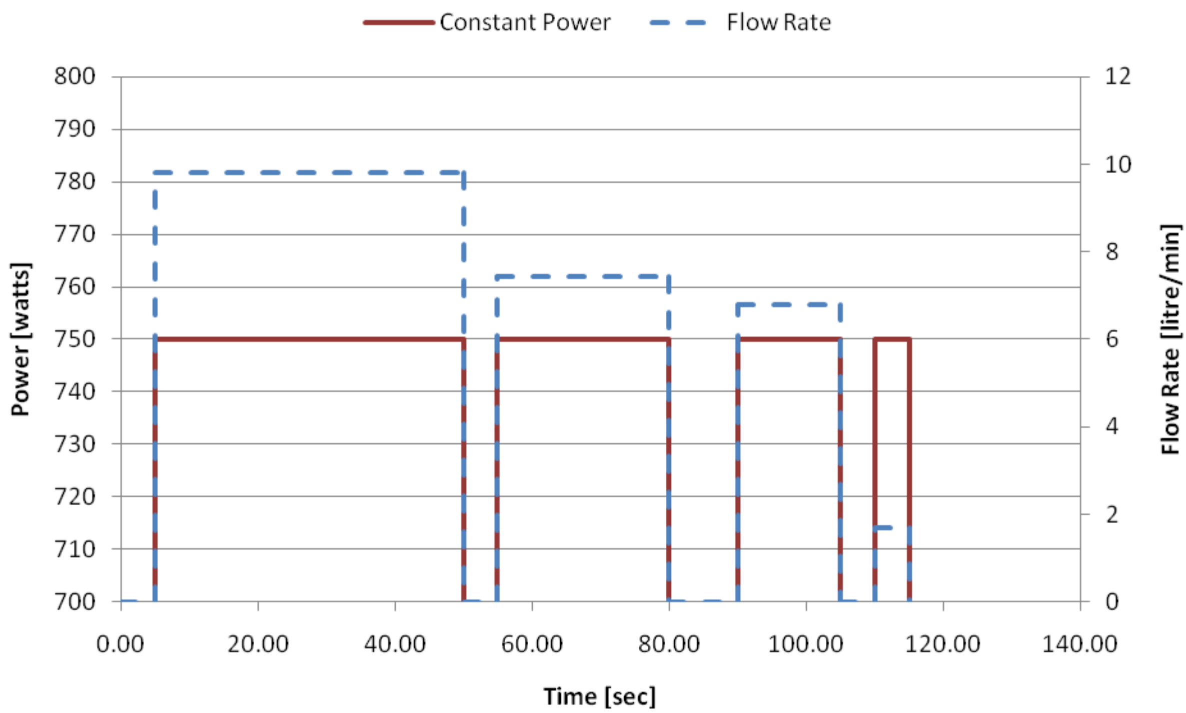


Figure 6-2 Example plot of constant-power pump flow rate and power consumption versus time



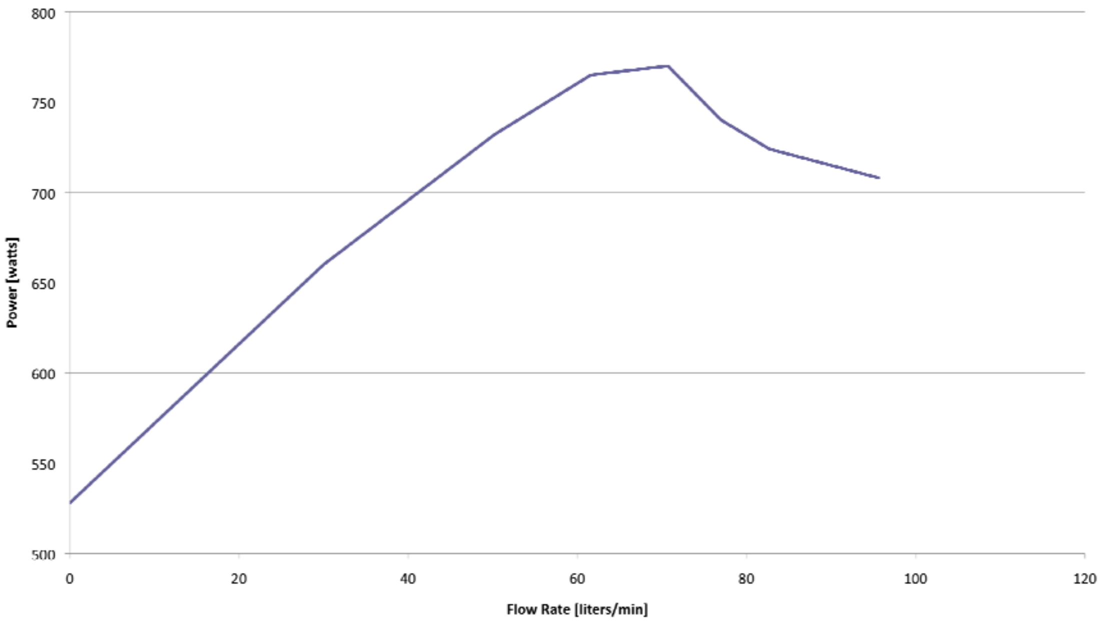
Note the Constant Power Pump is constant regardless of flow rate

6.2.3 PUMP MODELS DEVELOPED FROM PUMP TEST DATA

Aside from the constant power model, three other models were adapted from pump test data provided by a major pump manufacturer. Davey Water Products Pty Ltd provided specification data for three of their pumps. The test data was generated through a series of pump tests (based on "test stand data") conducted in the Davey laboratories.

Pump power curves were developed using the performance data provided by Davey for the three types of pumps. The data was fitted to polynomial regression curves, and these curves were used to predict the power consumption for the flow data. An example of one of the pump power curves used is shown in Figure 6-3 below. See Appendix C for all three pump power curves used in the analysis.

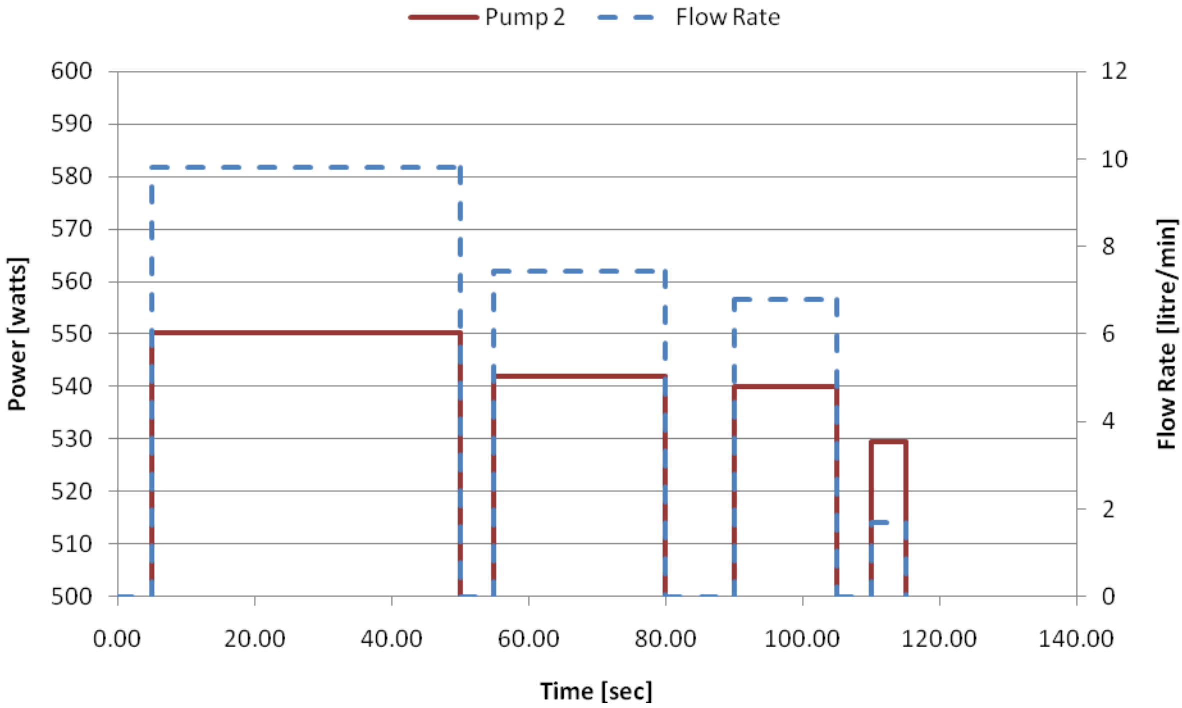
Figure 6-3 Example of a pump power curve for a rainwater tank pump (Davey Water Products, 2008)



The power curves used in this analysis were the three most commonly used rainwater tank pumps from Davey (Lance 2008). Pump 1 is frequently used for homes requiring pumps for garden and irrigation, Pump 2 is most commonly paired with the Rainbank system and is used in households where rainwater is required for indoor and outdoor uses (such as toilets, laundry and garden) and Pump 3 (HS50-06-1) is the pump type used at two of the houses that were monitored as part of this research project (see Empirical Analysis in Chapter 7).

The difference between the constant power pump model and the models taken from actual pump test data can be seen by comparing the constant power plot in Figure 6-2 with the plot of power usage by Pump 2 in Figure 6-4. Note that the power usage varies with each event, while the power usage is constant in the constant-power model.

Figure 6-4 Typical plot of Pump 2 flow rate and power consumption versus time



Note that Pump 2 power varies based on flow rate

6.2.4 RESULTS FROM PUMP MODELS

The water usage data sourced from YVW was used in the four separate pump models to simulate a single scenario where rainwater is used for **all** end uses. This enabled a comparison between the energy intensity predicted by the simple "constant power pump model" and the pump models developed by a pump manufacturer. The modelling results showed that the estimated energy intensity for pumps with similar power usage varied slightly between households. The results also showed that the constant power pump model consistently estimated energy intensity to be higher than that predicted by the models from the pump manufacturer. This result is reasonable as this model has the highest power consumption for all the pumps at typical household water flow rates. The differences can be seen by comparing the results in Table 6-1 for the three houses A, B and C.

In the final column of Table 6-1**,** the energy intensities calculated for each pump model have been averaged across the three houses. These averages for pumps 1, 2 and 3 show a variation in energy intensity of between 0.9 and 1.4 kWh/kL depending on the power used by each pump. The average intensity estimated by the constant power pump model was 1.5 kWh/kL.

Table 6-1 Calculated energy intensities of rainwater pumping systems for three houses using four pump models

Model used	Nominal motor power	House A (kWh / kL)	House B (kWh / kL)	House C (kWh / kL)	Average (kWh / kL)
Constant power model	750 watts	1.4	1.6	1.4	1.5
Pump 1	500 watts	0.8	0.9	0.8	0.9
Pump 2	770 watts	1.0	1.2	1.1	1.1
Pump 3	890 watts	1.3	1.5	1.3	1.4

It is important to note the difference in energy intensity between pumps with different power usage as this has implications for pump selection. For example, Pump 3 uses 60% more energy per kilolitre than Pump 1 and if the water pressure supplied by Pump 1 is sufficient for the application and Pump 3 is chosen, this energy is being used unnecessarily.

The data was also disaggregated according to end use, so that, for example the average energy intensity was calculated for toilet flushing events across all three houses. The average energy intensity for each end use, determined through each of the four pump models is shown in Table 6-2**.**

Table 6-2 Results from four models estimating average household rainwater system energy intensity

Model used	Nominal motor power	Energy intensities (kWh/kL)							
		Average whole household	Faucets	Toilets	Clothes washer	Irrigation	Showers	Baths	Leaks
Constant power model	750 watts	**1.5**	2.9	2.7	0.9	0.8	1.0	0.8	96.4
Pump 1	500 watts	**0.9**	1.8	1.7	0.5	0.4	0.6	0.4	64.0
Pump 2	770 watts	**1.1**	2.1	1.9	0.7	0.6	0.8	0.6	67.9
Pump 3	890 watts	**1.4**	2.6	2.4	0.9	0.8	1.0	0.8	80.0

The lowest energy intensity end uses are clothes washers, irrigation systems, showers and baths. This is due to the fact that these are events where taps and valves are opened fully and run continuously for a period. Flow rates are higher and more continuous (i.e. there are fewer stops and starts) with these types of water use events, unlike toilets and faucets, where toilet cisterns trickle and fill slowly and faucets are turned on and off. These two end uses had higher energy intensities associated with them. The relatively high energy intensity of toilets has interesting implications, as it is one of the most commonly connected end uses, after outdoor water use, for rainwater systems.

Only one of the case study houses had a dishwasher, which was found to have a high energy intensity. This is most likely due to the stop/start nature of a dishwasher, which uses more energy through pump start ups. However, as there was only one result, it has been omitted from the above table.

The energy intensity is higher for water usage events that have lower flows. This is demonstrated by the extremely high energy intensities associated with leaks as shown in Table 6-2 above. High flow uses will allow the pump to operate at its best efficiency point (BEP), maximising pumped water for energy input. Low flow events will cause the pump to operate below the BEP, and the pump will use substantially more energy to pump an equivalent amount of water. For a low flow, a real pump will use slightly less power at any time, but will need to operate for longer to pump an equivalent amount of water. This longer run time leads to the higher energy usage per volume of water pumped.

6.2.5 DISCUSSION

It may be difficult for the consumer to choose a pump based on power usage alone as power and energy efficiency do not directly correlate. An 890 W pump uses about 80% more power than a 500 W pump, but the energy intensity associated with the 890 W pump is only 60% greater than the energy intensity associated with the 500 W pump. The difference in energy intensity between these two pumps can be largely attributed to the shape of the power curve, which illustrates the variation in power usage according to flow rate (for example, see Figure 6-3). In other words, a pump should be chosen to match the flow rate. For example, if the typical flow rate of end uses in a household is 5 litres/minute, then an energy-efficient pump will use low energy when pumping at 5 litres/min.

In practice, matching a pump to its load in a household rainwater system is difficult. Frequently, household residents do not know the water consumption profile of their appliances, taps and other end uses. Additionally, householders are not aware of which end uses are used most or least frequently. There may also be a broad range of flow rates that need to be provided for by the rainwater pump, and a pump is almost always most efficient at a single flow rate. For example, if a toilet cistern draws 5 litres/min, a clothes washer uses 10 litres/min, and irrigation is preferred at 20 litres/min, it is not possible to optimise a single-speed, typical rainwater pump to this application. A further complication is that pump manufacturers do not typically publish their power curves, which makes selecting an efficient pump a challenge even for the more knowledgeable purchaser.

The importance of proper water system maintenance is demonstrated by the extremely high energy intensity associated with leaks for all pump models.

7 EMPIRICAL ANALYSIS

In order to validate and compare the theoretical energy intensities that were calculated in Chapter 6, a small number of single dwelling households with rainwater systems were selected for monitoring in this research project. Due to the small scale and short timeframe of this component of the research project, households were selected using ISF contacts. Selection criteria included:

- accessibility;
- type of pump (variable speed, fixed speed, submersible);
- type of mains water connection (trickle top-up, valve or switch); and
- number of people per household (typically 4 people).

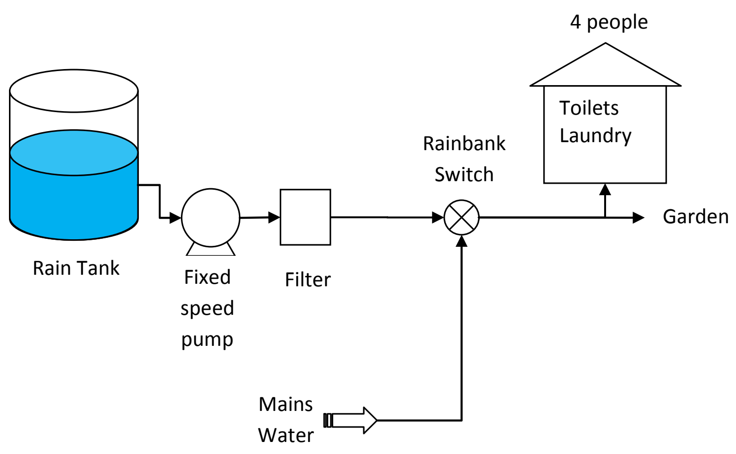
Descriptions of the dwellings that were monitored are provided below.

7.1 TEST SITE DESCRIPTIONS

Site 1 – Balmain Terrace

This terrace house is home to a family of four people that use rainwater to supply their two toilets, washing machine and garden. The rainwater system consists of a 50 m^2 roof catchment area, a 4 kL rainwater tank, a fixed speed Davey pump and a Rainbank mains water switch. This system is illustrated in the schematic in Figure 7-1.

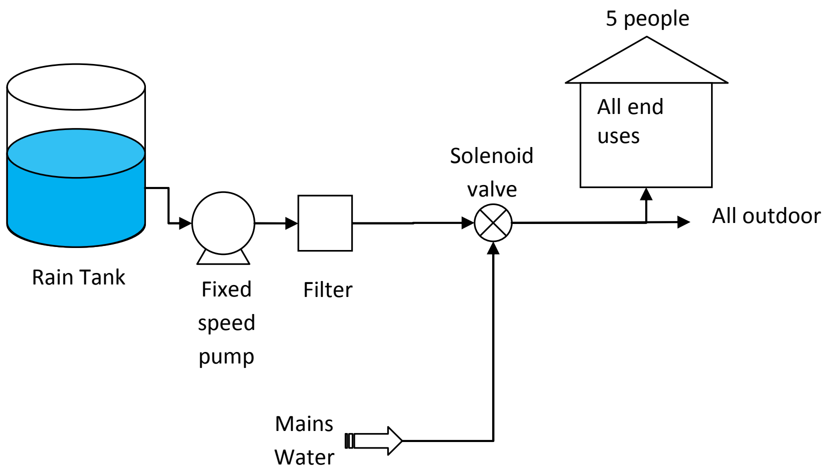
Figure 7-1 Balmain House system schematic



Site 2 – Newtown Terrace

A family of five lives in this terrace house in Newtown, which has a rainwater harvesting system collecting rainwater from the roof as well as the neighbour's roof, providing a total catchment area of 211 m^2. The system is unusual in that rainwater is used to supply all household end uses and a special venturi jet pump is used to draw rainwater from both a storage bladder beneath the house and a standard rainwater tank. The total rainwater storage is 6 kL and the system uses a solenoid valve to switch to the mains water supply when required. However, the large rainwater storage means that the system operates almost independently of the mains water supply. This system is illustrated in the schematic in Figure 7-2**.**

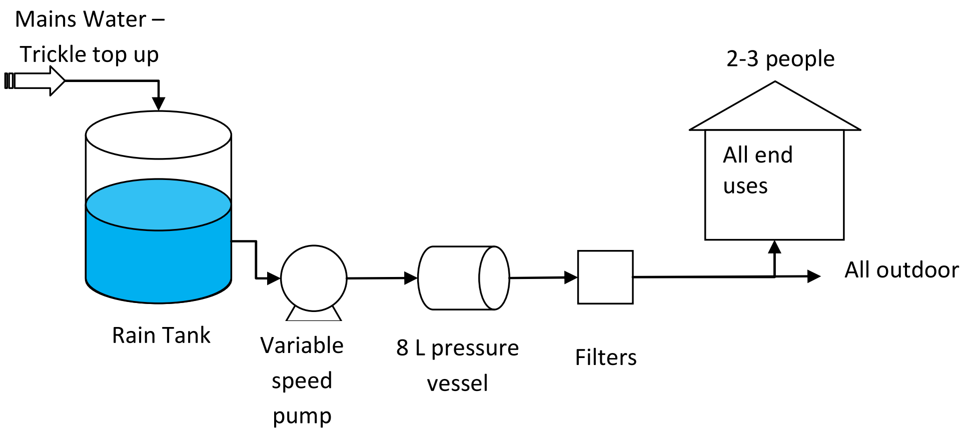
Figure 7-2 Newtown house system schematic



Site 3 – Newcastle House No. 1

This freestanding house in Newcastle has a roof area of 175 m^2 and a household of 2 to 3 people. Rainwater is used to supply all end uses within the house and the tanks are kept topped up by a float-activated trickle top-up system. The rainwater system has 6.7 kL of storage and uses a variable speed pump. An eight litre pressure vessel is paired with the variable speed pump by the manufacturer.

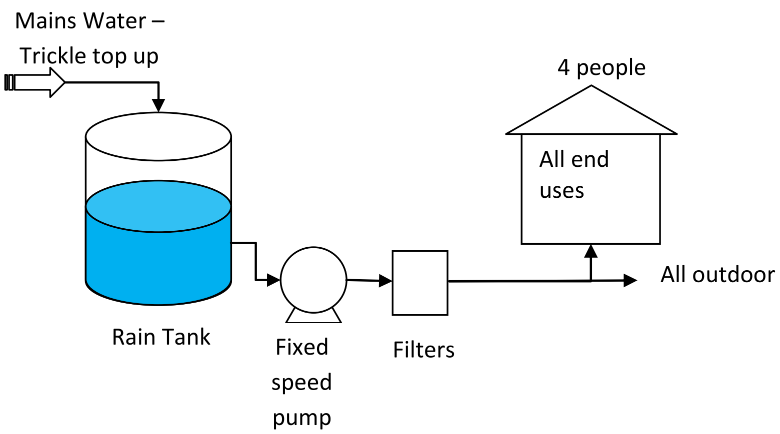
Figure 7-3 Newcastle House No. 1 system schematic



Site 4 – Newcastle House No. 2

This house in Newcastle has a 210 m^2 roof catchment area and 8.1 kL of rainwater tank storage. The tanks are topped up by the mains using a trickle feed system, which is triggered by a float valve. Rainwater is delivered to all end uses through the use of a fixed speed pump.

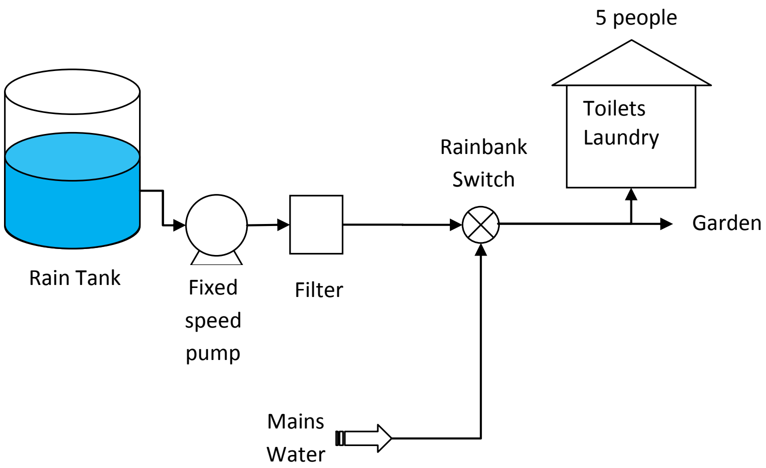
Figure 7-4 Newcastle House No. 2 system schematic



Site 5 – Padstow House

This suburban house has a 10 kL rainwater storage system fed by a roof catchment area of 175 m^2, where rainwater is used for one toilet, a washing machine and outdoors. Mains water backup is provided through a Rainbank switching system.

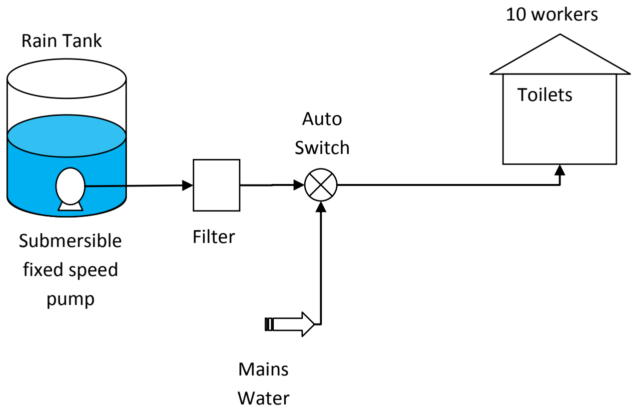
Figure 7-5 Padstow house system schematic



Site 6 - Redfern Office

This small inner city office has 10 employees that use 2 toilets. Rainwater is used for toilet flushing and is stored in three 2 kL tanks which drain 170 m^2 of roof area. Mains water backup is provided through a Rainbank switching system.

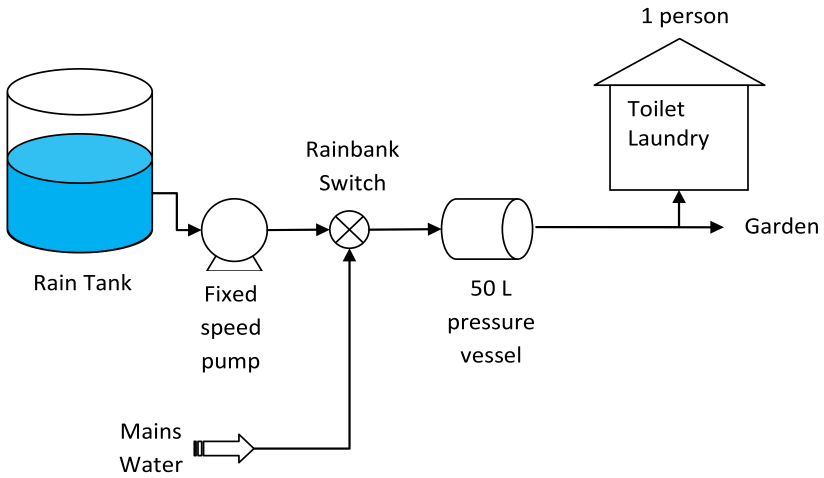
Figure 7-6 Redfern Office system schematic



Site 7 – Enmore Terrace

The owner of this terrace house in Enmore uses rainwater to flush toilets, water the garden and for the washing machine. The system consists of a 2 kL rainwater storage, a fixed speed pump, an automatic switching system and a 50 L pressure vessel.

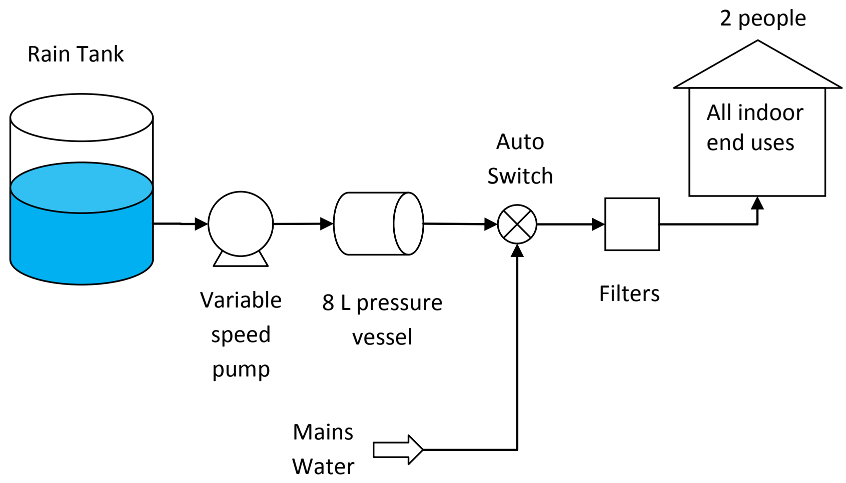
Figure 7-7 Enmore Terrace system schematic



Site 8 – Concord

At this freestanding house at Concord, 12 kL of rainwater storage and a variable speed pump is used to supply rainwater to all end uses within the house. The pump manufacturer also specifies the use of an 8 L pressure vessel to be used in conjunction with the pump. After the pump an automatic mains switching device is used as a backup. Ceramic filters are used on the pipes servicing the kitchen and bathroom basins.

Figure 7-8 Concord House system schematic



A more detailed list of the features of each test site is provided in Table 7-1. Sites 2, 3 and 4 are unusual in urban areas as at these households rainwater is supplied to all end uses, with drinking water filtered. While these three systems do not necessarily represent typical household rainwater systems, monitoring such a broad range of systems which include characteristics such as fixed or variable speed pumps, mains switches or trickle top-up and the full range of end uses provides a rich data set.

A diagram has been created in Figure 7-9 to illustrate the range of possible rainwater system configurations and the configurations that were monitored at each household for this research project. This diagram defines each possible configuration by pump type, type of mains water backup and type of pressure assistance. The monitored houses have been placed on the diagram to indicate which configurations have already been monitored and which are planned. At some houses different combinations were tested, such as at the house at Newtown, where the existing system was tested with and without a pressure vessel. Further tests are also planned for Newcastle 2 and Enmore Terrace. The tests marked in green are tests that have been completed. The tests marked in blue are planned and the tests marked in pink may need investigation in the future.

Figure 7-9 Rainwater systems configurations map showing tests represented in this study

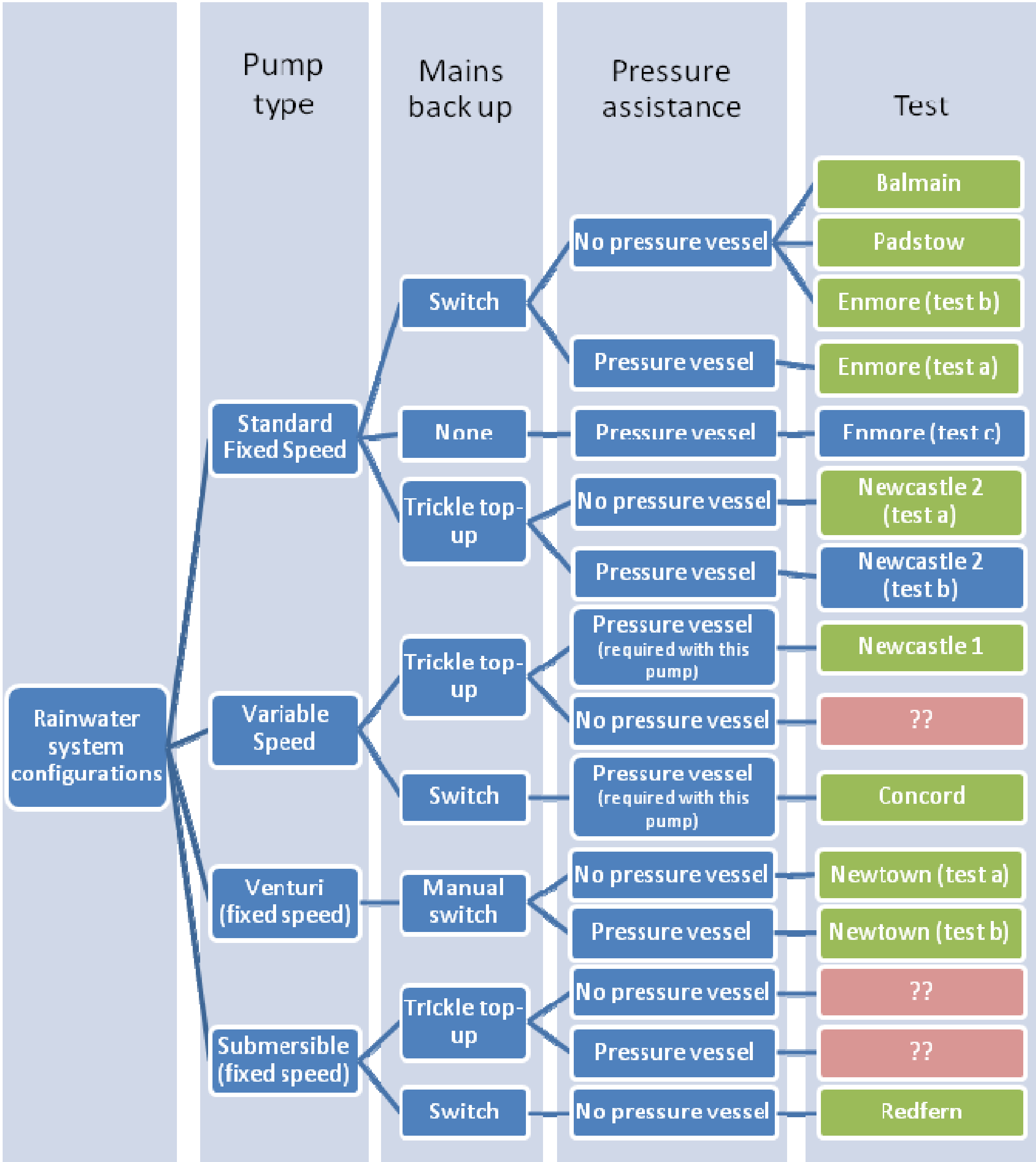


Table 7-1 Features of the rainwater systems, end uses and users at each test site (note: also continued on the next page)

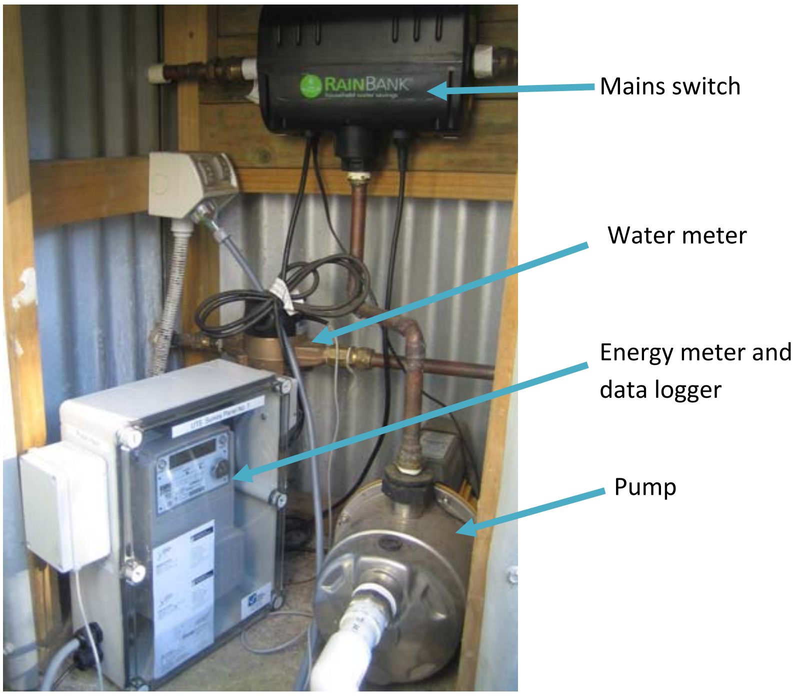
Characteristics	Balmain	Newtown	Newcastle 1	Newcastle 2	Padstow	Redfern Office	Enmore Terrace	Concord House
Total tank storage volume	4 kL	Tank & bladder with total storage approx. 6 kL	6.75 kL	8.1 kL	10 kL	6 kL	2 kL	12 kL
Pump type / model no.	Davey HS50-06L 890 W	RivaFlo (Onga) 2800 rpm Venturi jet pump 750 W	Grundfos CHIE 4-60 Variable speed with 8 L pressure vessel	Onga SMH55 with Presscontrol 550 W	Davey HS50-06 890 W	Davey Submersible	Davey HS50-06L-1	Grundfos CHIE2-60 PT Variable speed
Pump supply pressure			Initially 350, then 400, then 420 kPa	400 kPa				350 kPa
Roof catchment area	50 m²	211 m²	175 m²	210 m²	175 m²	170 m2	60 m2	190 m2
Type of switch to mains supply	Davey Rainbank	Solenoid valve, dual check backflow prevention	Apex RainAid mechanical float activated tank top-up	Apex RainAid mechanical float activated tank top-up	Rainbank-3	Davey Rainbank	Davey Rainbank	Bianco Rainsaver
Total number of people	4	5	2 to 3	4	5	10 workers (7 males, 3 females)	1	2
Teenagers	0	1	0	2	1	0	0	0
Smaller children	2	2	0	0	2	0	0	0
End uses supplied by raintank	Clothes washer, outdoor tap and toilet flushing	Whole house	Whole house	Whole house	Clothes washer, outdoor tap, toilet flushing	Toilets, urinals, some garden use	Toilet, laundry, outdoor	Whole house
Number of toilets	2	2	3	2	1 on mains, 1 on raintank	2	1	2
Toilet flush type	2 x 4.5/3 L (4 star toilets)	1 x 9/1.5 L retrofitted, 1 x 12 L	2 x 9/4.5 litre, 1 x 6/3 L	2 x 9/4.5 litre	1 x 10L single-flush toilet with 2L bottle	2 x 4.5/3 L (4 star) 2 x waterless urinals	1 x 4.5/3 L (4 star)	2 x 6/3 L
Appliance type – clothes washer	Front loading ASKA (4 star)	Washing machine 62 L BOSCH Maxx Classic	LG Intellowasher front loader (AAA rating)	Hoover 750 top loader (not rated)	Simpson 4-cycle, 2-speed, top-loader ~Approx. 140 L	N/A	Miele WT 2670	Hitachi PAF1260PX (older style top loader)
Appliance type – dishwasher	N/A	N/A	FP Dishdrawer 3 star WELS (14.7 L/wash)	Bosch 4 star WELS (13.7 L/wash)	N/A (D/W on mains)	N/A	N/A	Dishlex 150 Electronic
Showerhead type	N/A (shower on mains)	Aerator 6.5 L/min	2 x 8 L/minute	2 x 7 L/minute	N/A (shower on mains)	N/A	N/A (shower on mains)	Grohe (9 L/minute)

7.2 METERING EQUIPMENT

At each site, water and energy consumption of the rainwater supply systems were monitored and recorded by a data logger. Rainwater consumption was measured by the use of a Manu-Flo MES-MR flowmeter with nutating disc measurement and a pulse output of 61.5 pulses per litre. The pulse lead from the flowmeter was connected to the combined data logger and energy metering unit developed by Testing Certification Australia (TCA). The data was sampled to 1-minute resolution. An antenna attached to the data logger was used to transmit data via GPRS so that it could be downloaded remotely.

An example of the metering set-up is shown in the photograph below.

Figure 7-10 Field water and energy metering setup



7.3 METERING RESULTS

Monitoring of these rainwater supply systems was carried out between November 2008 and March 2009. For each test, monitoring was carried out for a period of at least 10 days.

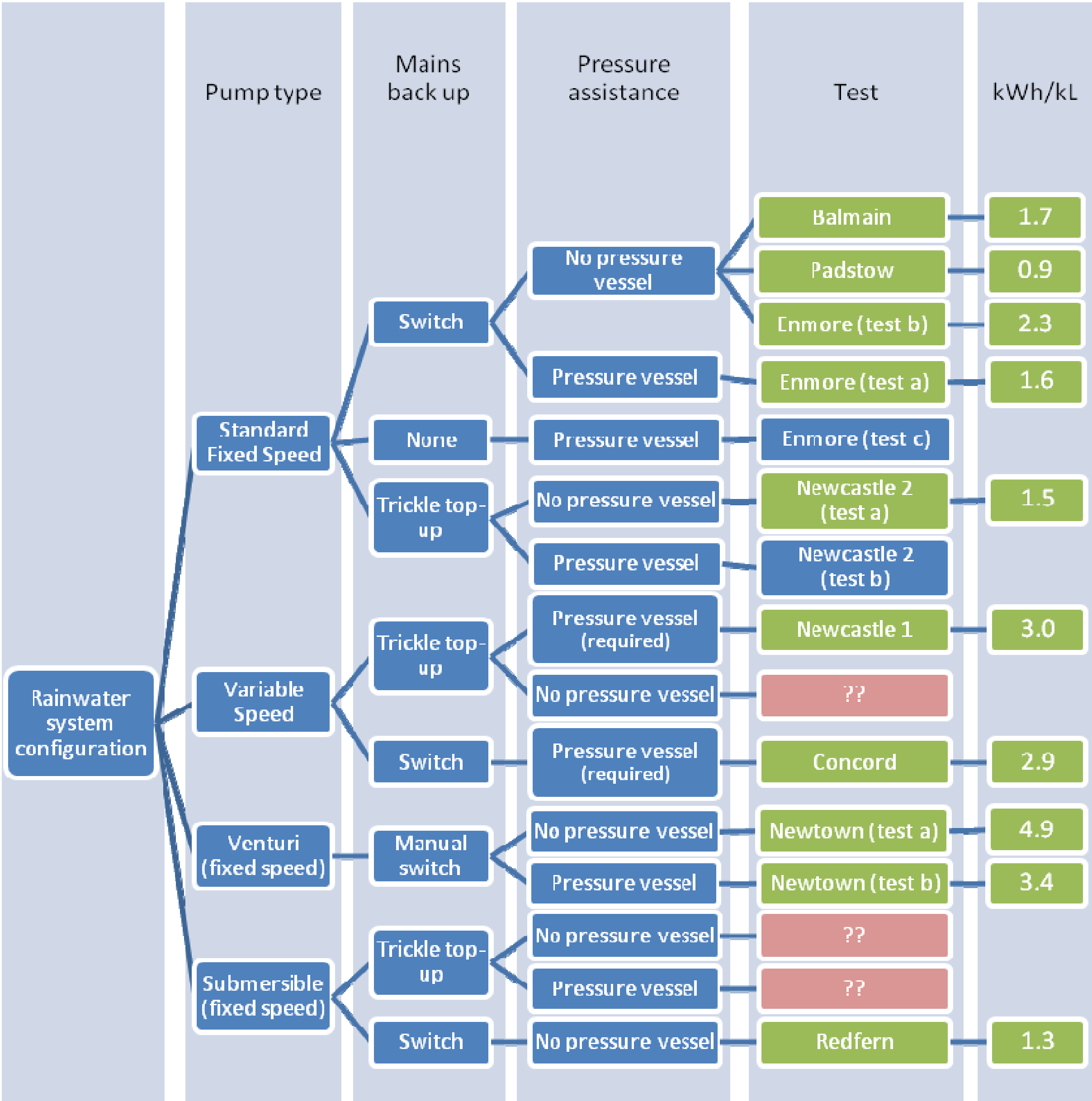
7.3.1 ENERGY AND WATER CONSUMPTION

The energy intensity or average energy consumption per volume of water supplied was determined for each test. The energy intensity, daily energy consumption and daily water consumption are set out in Table 7-2 along with a description of each system/test. These results have also been represented on the rainwater system configuration test map in Figure 7-10, which clearly sets out the differences between each rainwater system configuration.

Table 7-2 Monitoring results – average energy intensity of rainwater system configurations

Site	Test	Pump Type	Mains backup	Pressure Vessel	Energy intensity (kWh / kL)	Daily pumping energy (kWh / day)	Daily rainwater consumption (L / day)
Balmain Terrace		Fixed	Auto Switch	None	**1.7**	0.1	71
Newtown Terrace	Test A	Venturi (fixed)	Manual Switch	None	**4.9**	0.7	142
	Test B	"	"	Pressure vessel	**3.4**	0.4	123
Newcastle 1 House	Test A	Variable Speed Set point 350 kPa	Trickle Top Up	Pressure vessel	**3.8**	1.3	344
	Test B	Set point 400 kPa	"	"	**3.1**	1.1	371
	Test C	Set point 420 kPa	"	"	**3.0**	1.1	375
Newcastle 2 House		Fixed	Trickle Top Up	None	**1.5**	1.5	993
Padstow House		Fixed	Auto Switch	None	**0.9**	0.3	287
Redfern Office		Submersible (fixed)	Auto Switch	None	**1.3**	0.2	147
Enmore Terrace	Test A	Fixed	Auto Switch	Pressure vessel	**1.6**	0.04	22
	Test B	"	"	None	**2.3**	0.07	31
Concord House		Variable speed	Auto Switch	Pressure vessel	**2.9**	0.86	296

Figure 7-10 Rainwater system testing diagram with measured energy intensities at each site



7.3.2 KEY OBSERVATIONS FROM EMPIRICAL RESULTS

Key observations from the results of monitoring include the following:

- Newtown Terrace, which used a less common venturi type pump had the highest energy intensity (4.9 kWh/kL). However, this household also had very low daily water consumption: 142 L/day for all end uses for 5 people, which is significantly less than Newcastle 2, where 5 people used 993 L/day for all end uses.

- The installation of a pressure vessel at Newtown Terrace reduced the energy intensity of the water supplied by 30%.

- The house at Newcastle 2, which used a fixed speed pump and a mains trickle top-up system had a comparatively low energy intensity (1.5 kWh/kL). This result is consistent with the results from the other fixed speed pump systems (Balmain 1.7 kWh/kL and Padstow 0.9 kWh/kL), but differs from these systems in that it does not use a mains switching system and uses rainwater for all household end uses rather than just for toilets, outdoor and washing machines. It also differs from these systems in that it has the highest daily energy consumption due to pumping (1.5 kWh/day) and the highest water consumption (993 L/day).

- Balmain Terrace and Padstow House had similar systems in that both used rainwater for irrigation, toilet flushing and clothes washing and had a similar number of residents; four and five respectively. Balmain had a higher energy intensity (1.7 kWh/kL) compared to Padstow (0.9 kWh/kL), but also had much lower water consumption (71 L/day) compared to Padstow (287 L/day) for the same end uses. Balmain also had a lower daily energy consumption due to pumping (0.1 kWh/day) compared to Padstow (0.3 kWh/day). This indicates that households that use greater volumes of water for each end use event (i.e. a combination of both behavioural and technical inefficiency) are likely to have a lower overall energy intensity for their rainwater supply system but higher water and energy usage.

- Enmore Terrace is similar to Balmain Terrace in that both have a fixed speed pump and switching system and both have highly efficient appliances and fittings. The energy intensity at Enmore (2.3 kWh/kL without pressure vessel and 1.6 kWh/kL with pressure vessel) was similar to that at Balmain (1.7 kWh/kL). Both houses recorded higher energy intensity than Padstow House, but both used considerably less water and pump energy on a daily basis.

- When the pressure vessel was removed from Enmore Terrace, the energy intensity of the rainwater system increased by 32% from 1.6 kWh/kL up to 2.3 kWh/kL, which suggests that the pressure vessel helps to reduce energy consumption at this site. The average water used in the first period was 22 L/day and in the second period it was slightly higher at 31 L/day. There may have also been some variation in end uses between the two periods. Rainwater is only used for toilet flushing and clothes washing in this house and if there has been some variation in the number of washing loads between the two sampled periods, then the overall energy intensity is likely to be affected. These variations would need to be controlled in order to determine the effectiveness of the pressure vessel.

- The submersible pump at Redfern with the mains switch was the same make as the other fixed speed pumps that were tested at Balmain and Padstow. The energy intensity of the system at Redfern (1.3 kWh/kL) was also similar to the energy intensities of those fixed speed pumping systems, 1.7 kWh/kL at Balmain, 1.6 kWh/kL at Enmore and 0.9 kWh/kL at Padstow.

- At the Newcastle 1 house, a variable speed pump which had been recently fitted required calibration by the pump manufacturer. Initially, the system had an energy intensity of 3.8 kWh/kL and the pump was regularly cycling on and off when there was no water flowing. This was thought to be due to the pump pressure being set below its design intention. Consequently, the pump's pressure set point was increased from 350 kPa to 400 kPa and the tolerance interval was increased from 5% to 10%. This stopped the pump from cycling on and off unnecessarily and reduced the energy intensity down to 3.1 kWh/kL. At a later stage the pump pressure set point was further adjusted to 420 kPa to increase flow for end uses on the second floor of the house. This increased the flow rate and the energy intensity dropped slightly to 3.0 kWh/kL. Another rainwater system that uses a variable speed pump has been tested at a house in Concord.

- The variable speed pump used at Newcastle 1 was found to use 0.1 kWh/day while on standby.

- The rainwater system with a variable speed pump at Concord had an energy intensity of 2.9 kWh/kL, which is very similar to the result recorded at Newcastle 1 (3.0 kWh/kL), where a similar pump had been installed for the same range of end uses – both households used the variable speed pump for all domestic end uses. The energy intensity of these systems is twice the energy intensity of the rainwater system at Newcastle 2 (1.5 kWh/kL), which uses a standard fixed speed pump for all domestic end uses. However, it is difficult to compare these households as the household at Newcastle 2 has far higher rainwater consumption.

- At Newcastle 2, a 24 L pressure vessel was added to the existing system which included a fixed speed pump and trickle top up system to test the impact on energy consumption. However, the pressure settings of the pump and the pressure vessel were not matched and consequently the user experienced significant variation in water pressure, which became particularly evident during showering. This was an unacceptable loss of service and the pressure vessel had to be removed. This incident highlighted the difficulty in retrofitting a pressure vessel to an existing system. Many householders would not be aware of the need to buy a pressure vessel that matches the pressure settings on their pump. The coupling of pumps and pressure vessels by manufacturers may be useful if pressure vessels are to be used to their full advantage.

- Energy intensity is a function of the energy efficiency of a rainwater system as well as the nature of the end uses and the efficiency of water use within the household. In order to compare the energy efficiency of rainwater systems, certain characteristics such as the types of end uses and the level of household water efficiency need to be controlled. Therefore different rainwater configurations would most usefully be examined in a single household to control for these factors.

7.3.3 ANALYSIS BY END USE

The results from monitoring these households have been further grouped according to the end uses supplied by rainwater. In Figure 7-11, the water and energy consumption of households using rainwater for toilet flushing, laundry and outdoor end uses have been plotted alongside each other on the graph – Balmain Terrace, Padstow House and Enmore Terrace respectively. This graph shows the energy intensity of each system as well as the average rainwater and associated pumping energy consumed by each system on a daily basis. The graph also shows the results for Enmore Terrace both with and without the use of a pressure vessel. The households at Balmain and Padstow use the same fixed speed pump and switching system for the same end uses and both have similar household structures with 2 adults and 2 children at Balmain and 2 adults and 3 children at Padstow. For easy comparison of the statistics of these sites, refer to Table 7-1**.** Considering their similarities, it would appear that the difference in energy intensity between these two systems is due to the way rainwater is used at each house as distinct from the rainwater system technology.

The house at Padstow has a less efficient toilet and washing machine than the house at Balmain and the house at Padstow also has a larger rainwater storage and catchment area. More water is being used at Padstow, presumably due to the use of less efficient appliances, less efficient behavioural use of water and greater garden watering. This also drives up household energy consumption. However, due to the higher water usage and longer water usage duration of each end use event, the overall energy intensity of this system is lower than the system at Balmain. This example illustrates that the energy intensity of household rainwater systems is a result of a range of factors and is significantly affected by water use efficiency (both behavioural and equipment efficiency level). Some characteristics of water use at each house have been compiled in Table 7-3 to highlight the differences and how these may affect the energy intensity.

Table 7-3 Water use characteristics of three households with similar rainwater system configurations

House	Balmain	Padstow	Enmore
Characteristics of water use (data observations)	Mix of long and short duration events, mostly low flow	Longer duration, high flow events	Short duration, low flow events
Outdoor use	Garden watering	Significant garden watering	Almost no garden watering
Energy Intensity (kWh/kL)	1.7	0.9	2.3
Rainwater use per person (L/person/day)	18	57	31
Pump power (Watts)	890	890	890

Figure 7-11 Energy intensity and daily household water and energy consumption for households using rainwater for non-potable end uses (toilet, outdoor, laundry)

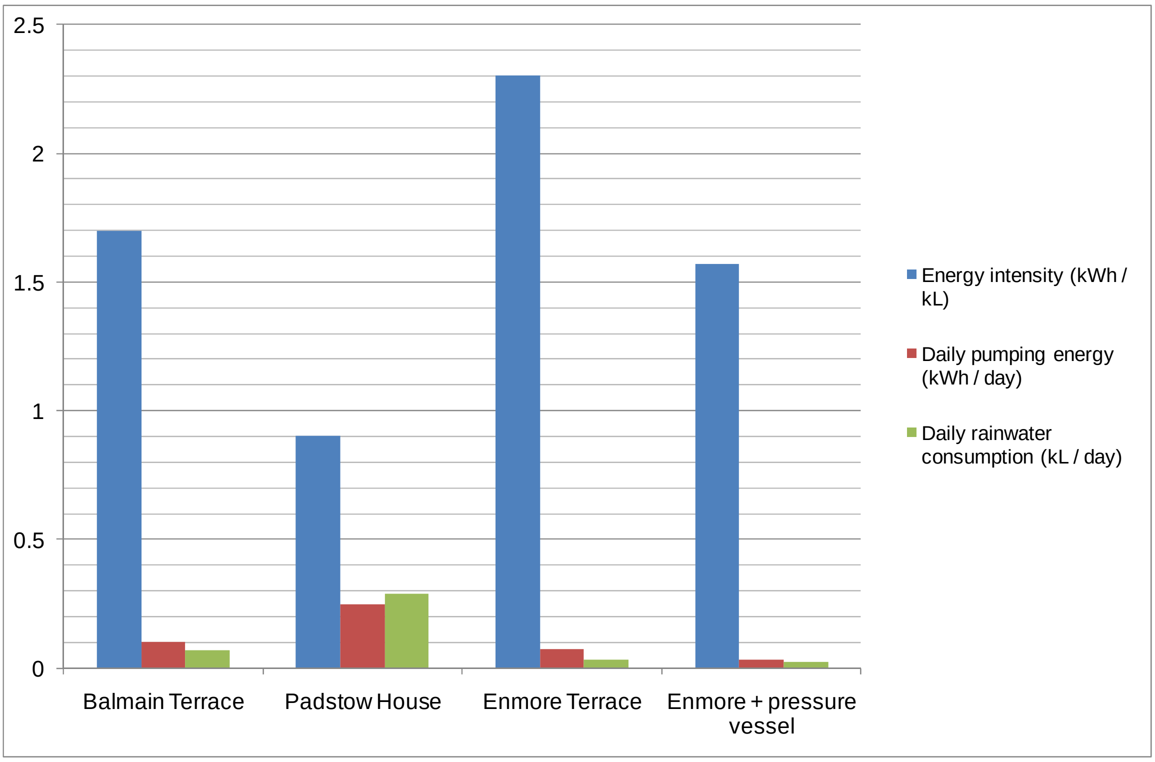
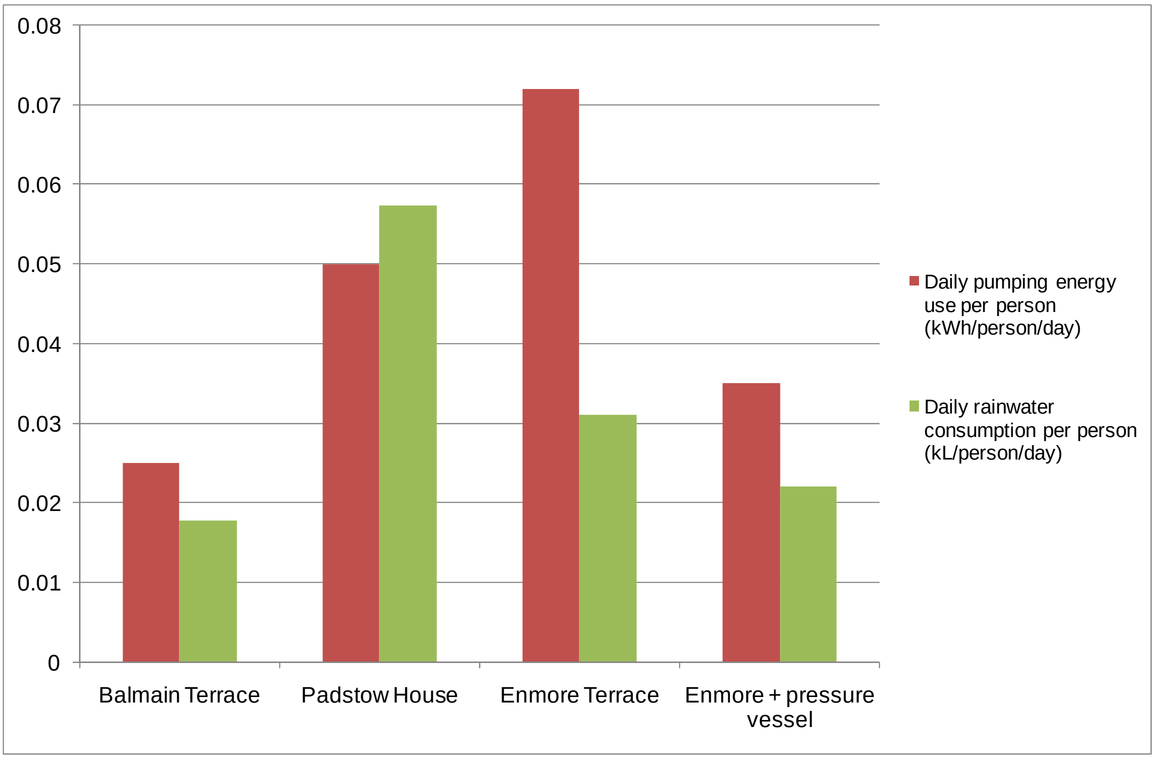


Figure 7-12 Daily water and energy consumption per person for households using rainwater for non-potable end uses (toilet, outdoor, laundry)



It is likely that the high flow, longer duration water use events at Padstow have contributed to the low energy intensity, as the pump may be operating at a more optimal rate. The lower flow rate water use events at Balmain use less water, but are probably less efficient in terms of the pump operation, which drives up the energy intensity. In the case of Enmore, rainwater was used almost exclusively for low flow, short duration events (i.e. toilet and washing machine), which means that the powerful pump was operating sub-optimally.

The difference in water use per person at each household can be seen in Figure 7-12**.** This graph shows the comparatively higher water use for Padstow when compared to Balmain and Enmore. The impact of adding a pressure vessel to the configuration at Enmore can also be seen in Figure 7-11 and Figure 7-12. The pressure vessel effectively dampens the effect of the many low flow end uses at Enmore to reduce the amount of energy used by the pump and consequently reduce the energy intensity by 32%.

The households using rainwater for all domestic end uses are more difficult to compare as each uses a completely different type of pump. The Newtown Terrace uses a venturi pump, Newcastle 1 uses a variable speed pump and Newcastle 2 uses a fixed speed pump. It would appear that the fixed speed pump at Newcastle 2 is the most efficient due to the low energy intensity. However, the graph in Figure 7-13 shows that this household uses a lot more water. Considering the similarities between Newcastle 2 and the Newtown Terrace, with a similar number of occupants, similar toilets and top loading washing machines, it would appear that the difference in water use is largely due to behaviour and outdoor water use. Again, the duration of water use events reduces the overall system energy intensity. In order to confirm the efficiency of the fixed speed pump relative to the other types of pumps, different pumps will need to be tested at each site. The graph in Figure 7-14 shows the water and associated energy consumption per person for each household and illustrates the difference in water use behaviour. The house at Newcastle 2 also uses more water per person than the other households which had much higher energy intensities. The differences in the energy intensities of these systems are likely to be due to a combination of factors, including the differences in pump types and the differences in water use behaviour.

Figure 7-13 Energy intensity and daily household water and energy consumption for households using rainwater for all domestic end uses

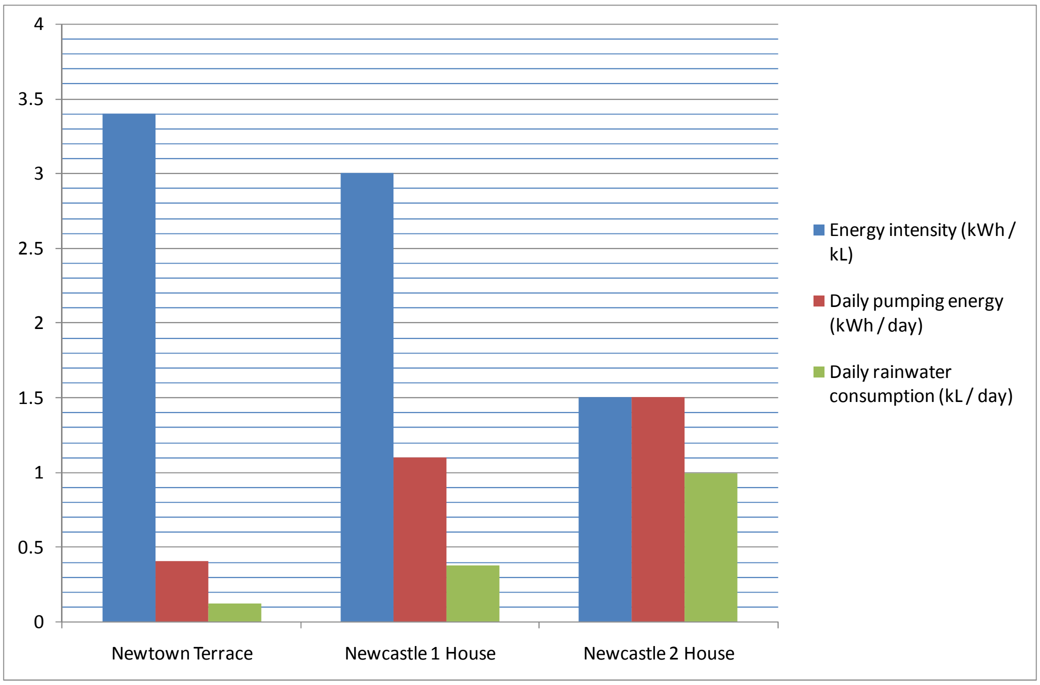
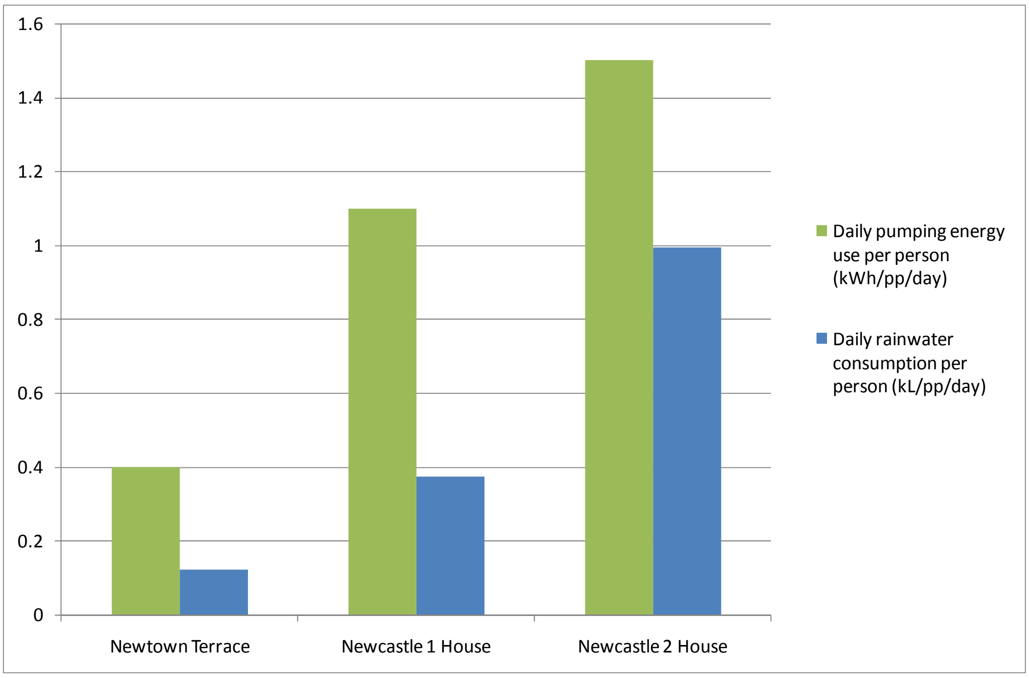


Figure 7-14 Daily water and energy consumption per person for households using rainwater for all domestic end uses



This analysis shows that low energy intensity for a rainwater system does not necessarily correlate with lower energy consumption overall. In fact, low energy intensity may be an indicator of greater household water use or greater use of rainwater for specific end uses such as irrigation which have a low associated energy intensity. It also shows that energy intensity is lower where the pump's output is matched to the flow requirements of the end use.

8 DISCUSSION OF THEORETICAL AND EMPIRICAL RESULTS

In this chapter, the energy intensities that were calculated in the theoretical analysis have been compared with the actual energy intensities determined from monitoring data. Further research questions arising from these analyses are also discussed.

8.1 COMPARISON OF THEORETICAL AND ACTUAL ENERGY INTENSITIES

One of the objectives of this investigation was to compare calculated theoretical energy intensities of rainwater systems with data from monitoring actual systems. A comparison table has been prepared in Table 8-1 using the calculations carried out in Chapter 6 and the data collected in Chapter 7. In this table, results from the theoretical pumping models that most closely match the monitored systems have been placed together. In the first comparison, Pump Model 1 which uses a 500 W pump to supply rainwater to all end uses has been compared with the results from the Newcastle 2 house which uses a 550 W pump to supply all end uses. In this case, the calculated theoretical energy intensity (0.9 kWh/kL) was much lower than the energy intensity for the actual system with similar characteristics (1.5 kWh/kL). This difference is greater than 50% and suggests that the energy intensity of a rainwater system may be significantly affected by user behaviour and/or actual pump configuration (as opposed to a pump operating in ideal conditions).

Table 8-1 Comparison between calculated and measured energy intensities

Model / Monitoring site	Nominal motor power (W)	End uses	Energy Intensity (kWh / kL)			
			House A	House B	House C	Average
Theoretical versus actual comparison 1						
Pump Model 1 (Theoretical)	500	All end uses	0.8	0.9	0.8	**0.9**
Newcastle 2	550	All end uses				1.5
Theoretical versus actual comparison 2						
Pump Model 3 (Theoretical)	890	Clothes washing, toilet & irrigation	1.1	1.3	1.2	**1.2**
Padstow	890	Clothes washing, toilet & irrigation				0.9
Balmain	890	Clothes washing, toilet & irrigation				1.7

In the second comparison, Pump Model 3 and its theoretical energy intensities for three different households (A, B and C) have been placed alongside the results from the monitored houses at Padstow and Balmain. While the theoretical model and both monitoring sites used the same pumping system for rainwater supply to the same end use types, each system had a different energy intensity. Again, this result illustrates how water use behaviour, household characteristics and the pump system configuration affect the energy intensity of a rainwater system.

Further monitoring is required in order to determine average energy intensities for rainwater systems with particular characteristics. To determine the efficacy of specific technologies it may be necessary to test a range of configurations in single households, so that water use behaviour and household characteristics are controlled. Alternatively, a large number of systems will need to be monitored to determine the statistical significance of certain configurations and their associated energy intensity.

8.2 FURTHER INVESTIGATION REQUIRED

The monitoring results have provided some preliminary conclusions but have also raised a number of questions for further study. Some key questions that require further investigation have been outlined below.

How much energy does adding a pressure vessel to an existing system save?

The highest energy intensity in this study was recorded at Newtown Terrace where a venturi pump is used to supply rainwater to all end uses. The initial phase of testing resulted in an energy intensity of 4.9 kWh/kL. After fitting a pressure vessel to this system in the second phase, the energy intensity dropped by 30% to 3.4 kWh/kL. Despite this reduction, the energy intensity of the system remained comparatively high and in addition, the householder complained that a strong variation in pressure was experienced when the pressure vessel was in place. The use of venturi pumps in rainwater systems is not common, so this is not an ideal example to demonstrate the effectiveness of a pressure vessel, but it does provide preliminary indications that pressure vessels may be effective at reducing the energy intensity of water use. This hypothesis is supported by the results of tests carried out at Enmore Terrace, where energy intensity was 32% lower with a pressure vessel in place. However, as discussed in Chapter 7, further tests will need to be required to control for variations in water use behaviour and also to examine the effectiveness of pressure vessels in systems that use trickle top-up or manual switching valves.

Are header tanks a viable alternative and how much energy would they save?

Header tanks are not common in urban/suburban rainwater systems. However, in rural areas they are commonly used. Could header tanks be effectively used in urban rainwater systems? Are pressure vessels or header tanks more practical and/or effective?

How much more energy does a trickle top-up system consume compared to an automatic switch?

Further investigation is required to determine the impact on energy consumption of the trickle top-up system compared with the mains switching system. A trickle top up system is expected to use more energy as it pumps a greater volume of water and wastes the kinetic energy embodied in the higher pressure mains water. However, the impact of this difference depends on the actual volume of top-up required. If rainwater storages are sufficiently large to supply the selected end uses, then top-up may only be necessary on rare occasions.

Switching systems are usually paired with the pump and may consume energy on standby. Other variables affecting the energy consumption of the trickle top-up versus switching system are the types of end uses to which the rainwater is dedicated and the behaviour of the end users. For this reason it will be important to compare the impact of these technologies on the same household, to minimise the number of variables being tested.

Are currently available variable speed pumps for household rainwater systems more energy efficient?

In theory, a variable speed pump would be more energy efficient than a fixed speed pump as it is designed to adjust its speed and flow rate according to water demand, while a fixed speed pump operates at a fixed speed and flow rate regardless of demand. However, in the two tests that were carried out as part of this research project, households using variable speed pumps were found to have much higher energy intensities (3.0 kWh/kL at Newcastle House 1 and 2.9 kWh/kL at Concord) than rainwater systems using fixed speed pumps (0.9 – 2.3 kWh/kL). The households at Newcastle 1 and Concord use the same make of variable speed pump, so further testing of other commercially available variable speed pumps will be required.

In addition, both variable speed pumps that were tested required calibration of the pressure set point and tolerance interval to reduce energy consumption as in both cases the pump was cycling unnecessarily in between water use events. This implies that variable speed pumps need to be optimised to match the demands of the system. Further investigation may be required to determine the optimal use of variable speed pumps for household applications.

Are there any barriers to the implementation of more efficient rainwater supply systems?

Further study will help to define the features that are required to create a more energy efficient rainwater system. Once these features are positively defined, how can their use be effectively promoted? How can rebate criteria, development consent conditions (e.g. BASIX) requirements and other standards be influenced? Are there any other barriers such as social acceptability or availability of technology? Can manufacturers be engaged to improve certain technologies or system packages sold?

9 POTENTIAL BROAD-SCALE IMPLICATIONS

A key reason for undertaking this research project was to investigate the impact of the increasing use of distributed water supply systems on the energy intensity of water use. Specifically, there is an interest in the use of rainwater tanks to supplement urban water supplies. Their use is increasingly prevalent due to rebates and regulations (refer to Section 2.2). If this issue is not investigated now then current policy could be locking in high energy intensity options with associated inefficiencies in the way we provide water services into the future, which will be difficult to control and/or manage as part of a distributed system. This chapter briefly explores this issue using currently available information. It also looks at the differences between theoretical and actual energy usage in pumps, some of the potential reasons for these discrepancies and what might be done to improve efficiency.

9.1 IMPLICATIONS FOR CITY WIDE USE OF RAINWATER SYSTEMS

Regulations for the water efficiency of houses, such as BASIX[5] in NSW will have major implications in terms of the number of rainwater tanks installed over the coming years, as previously indicated in Figure 2.3 (i.e. 325,000 new houses by 2030). The energy intensity of water service delivery could therefore change significantly causing additional average and peak energy constraints not currently being considered.

Kenway notes that in drought years (such as 2006–07) when Sydney pumps from the Shoalhaven River, supplied energy intensity is 1.03 kWh/kL (Kenway et al. 2008). In more typical (non-drought) years, such as 2000–01, the energy intensity is much lower at 0.25 kWh/kL. Assuming that water is pumped from the Shoalhaven only 1 out of 10 years, the long-term average energy intensity of water service provision for Sydney would be approximately 0.33 kWh/kL[6]. The energy intensity for a typical pumped rainwater system from the investigations undertaken as part of this research project is 1.5 kWh/kL, yielding an energy intensity that is approximately 1.17 kWh/kL more for rainwater than for mains water. The addition of a 250 ML/d desalination plant in 2010 will increase the energy intensity of the water supply in Sydney, with the magnitude dependent on the operating regime for the plant. At full operation of the desalination plant, this would increase the long-term average energy intensity of the water supply to approximately 0.9 kWh/kL.

It is also worth noting that these results apply to Sydney, which has a relatively low energy intensity of water supply, due to gravity supply from the major storage (Warragamba Dam). In Adelaide, as indicated in Chapter 3, the energy intensity of water supply was 1.84 kWh/kL in 2006–07 due to significant pumping energy use during the drought, and therefore the average rainwater tank system would save energy relative to scheme supply.

Given that the water sourced from rainwater in an average BASIX house is calculated to be 53 kL/year (see Appendix B), an additional 62 kWh/year is required for the average BASIX house that uses a pumped rainwater system. This is equivalent to the annual average use of energy for a household

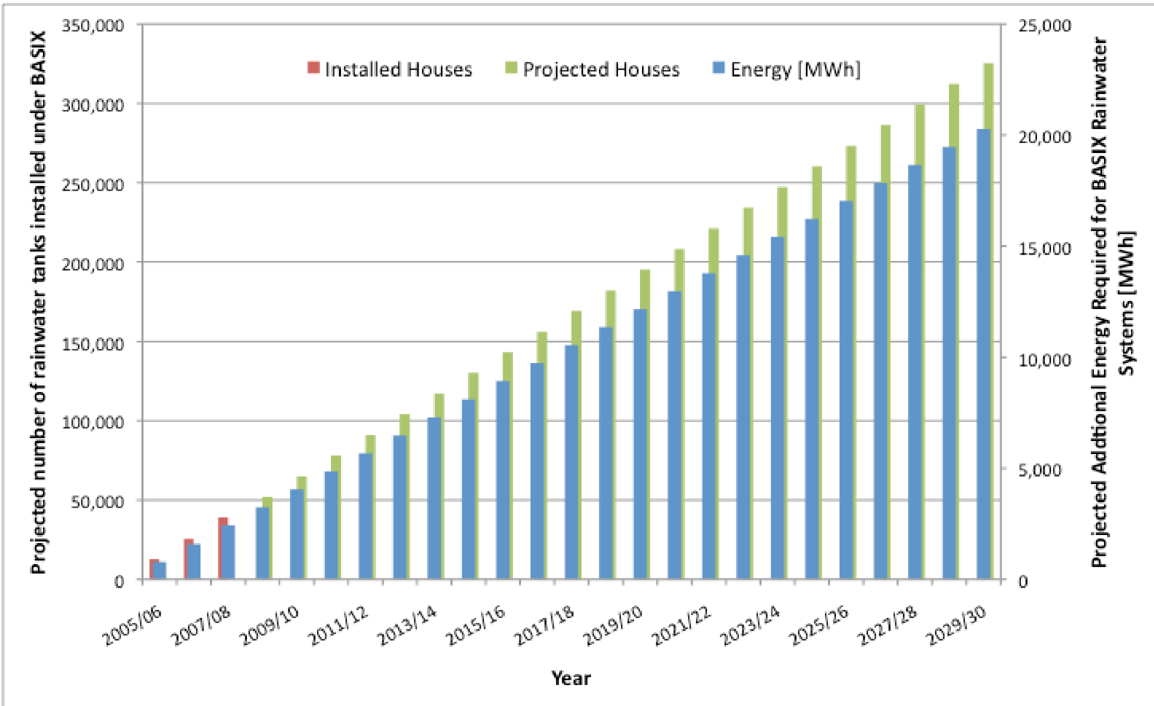
---

[5] BASIX, or Building Sustainability Index, places performance requirements on new houses for energy and water efficiency (see http://www.basix.nsw.gov.au/)

[6] Net energy intensity = (1.03 kWh/kL x 10%) + (0.25 kWh/kL x (1-10%)) = 0.33 kWh/kL. Note that this does not include the impact of the desalination plant which is under construction at present, which could raise the energy intensity to approximately 0.9 kWh/kL if operated at full capacity regardless of dam storage levels.

vacuum cleaner. The additional energy required to pump water in the new rainwater systems is shown in Figure 9-1 below.

Figure 9-1 Projected energy demand due to BASIX rainwater tanks



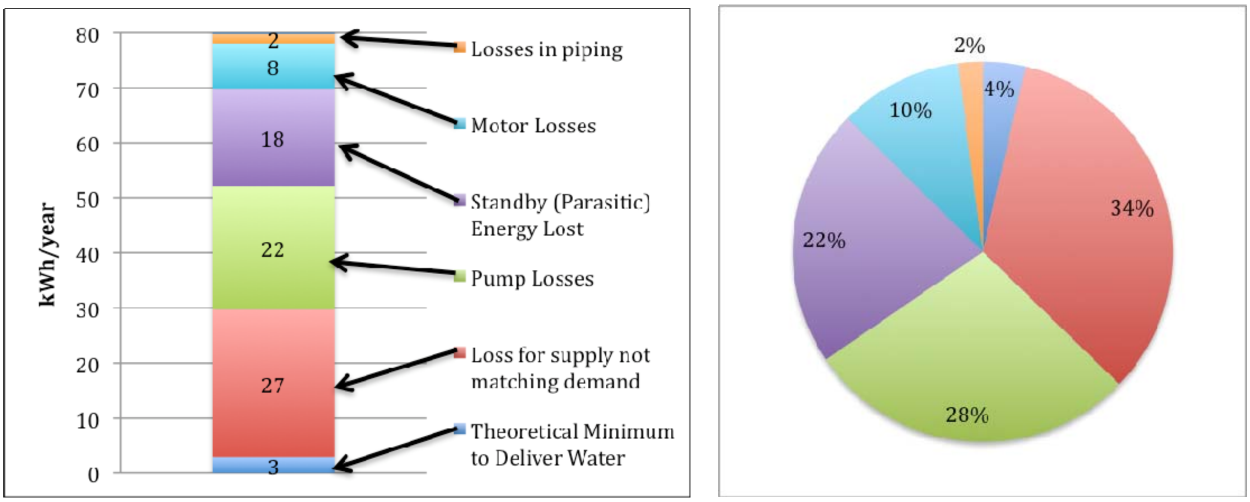
If these trends continue, by 2030 the total amount of additional energy used in Sydney, as a result of the projected additional 325,000 rain tank systems, will be 20,000 MWh/a, or approximately 20,000 tonnes/a of greenhouse emissions. This is equivalent to putting an additional 6,500 cars on the road.

However, this is not inevitable, and one of the main goals of this research is to determine what would need to happen to reduce the energy intensity of the water pumping task for distributed water supply systems, by reducing pump energy use and therefore to eliminate or reduce the marginal change in energy intensity of water use that results from distributed water supply systems such as rainwater tanks. The outcomes of some of these investigations are outlined in Section 9.2 and in Chapter 10.

9.2 IMPLICATIONS FOR PUMP DESIGN

Some of the differences between theoretical and actual pumping energy use observed as part of this research project may be attributed to inefficiencies associated with the small pumps used in rainwater systems. In the graphs in Figure 9-2, the losses associated with a typical rainwater pumping system have been illustrated.

Figure 9-2 Summary of pump efficiency and losses in a rainwater system



The pie chart shows the percentage of the total energy consumed by the pump that is lost or productively used. The column chart displays the total energy that is estimated to be consumed by a typical rainwater pump annually, to supply approximately 53 kL/household per year, which is an estimate of the use by a typical new house in Sydney that is compliant with development consent conditions for rainwater tank use.

These figures have been derived from a combination of available data and where data gaps exist, engineering experience as discussed in Appendix B. These figures show a surprisingly low level of pump efficiency, (i.e. only 3 kWh/year are theoretically required to transfer 53 kL/year, yet a further 77 kWh/year are consumed in the process). These graphs break down the ways in which energy is lost during pumping, which aids in determining where improvements in efficiency can be made. Some of the losses shown here such as losses in piping, motor losses and standby loss are difficult to remedy. However, pump losses can be minimised through pump design (28% of overall energy consumed) and losses associated with supply not matching demand (representing 34% of energy consumed) can be remedied through better pump selection. These losses are explained briefly below.

- ***Standby power*** is a constant loss and if the system is plugged into an electricity supply, there are losses regardless of whether the system is pumping water or not. Efficiency gains can be achieved by improving the circuitry design and minimising the current draw of the various sensors and electrical components.
- ***Motor losses*** can be minimised by improved manufacturing techniques that reduce tolerances on mechanical equipment and improve the electrical systems.
- ***Pump losses*** for small pumps can be reduced by improved mechanical design, with tighter tolerances during manufacturing. One of the major contributors to inefficiency in a pump is the spacing between the casing and the impeller blades. Reducing the spacing will improve the efficiency, but the impeller can only be as close as the design tolerances on manufacturing equipment allow. If the impeller is too close to the casing, the impeller may contact the casing and the pump will fail.
- The greatest improvement in rainwater system efficiencies can be achieved by ***matching the supply from the rainwater pumps to the uses for a household***. Pump systems are traditionally sized and selected by selecting the pump with the highest desired flow rate and the highest desired pressure. In the case of rainwater systems, the highest flow rate is

typically for the irrigation system, around 20 to 30 litres per minute (L/min). The pressure is selected to be similar to minimum mains water supply, which is around 20 to 30 metres head of water. The efficiency problem occurs when the same system is connected to an end use that does not require the same pressure/flow rate, and there is a mismatch between supply and load, for example where the pump is supplying rainwater to a toilet which requires a flow rate of only 5 L/min. The resulting system may be quite efficient for irrigation, but will be poorly suited to the other uses, generating a low efficiency system overall.

As indicated, the energy efficiency of rainwater systems can be improved significantly through improvements in pump design, better pump selection and potentially better alignment between the pump chosen and end uses being served. Due to the significant inefficiencies and thus huge potential to improve these efficiencies, this provides a major opportunity for pump manufacturers and distributors to improve efficiency and for specifications and regulations associated with pumps to be modified.

10 SUMMARY AND WAY FORWARD

10.1 SUMMARY OF FINDINGS

This chapter summarises the findings from both the theoretical and empirical components of this research project on rainwater system energy and water consumption.

Theoretical modelling of rainwater system energy consumption using real household water data, and including losses, found energy intensities that ranged from 0.8 kWh/kL for a 500 watt pump up to 1.6 kWh/kL for a 750 watt pump. These theoretical calculations found similar energy intensities to those determined through monitoring of fixed speed pump rainwater systems. However in some cases the actual empirical energy intensities were found to be up to 50% higher than those determined through theoretical modelling.

Rainwater systems using fixed speed pumps appear to be commonly used and were therefore investigated as part of the empirical component of this research project. Fixed speed pumps, in combination with either an automatic switching system or a trickle top-up, are becoming increasingly popular and represent the majority of systems installed for single detached dwellings. Based on the empirical results of this research project, it can be seen that these systems had the lowest energy intensities during monitoring, ranging between 0.9 – 2.3 kWh/kL. Much higher energy intensities were recorded for rainwater systems using either a variable speed or venturi pump (2.9 – 4.9 kWh/kL respectively), both of which are currently less common systems. A submersible pump, which is essentially a submersed fixed speed pump, yielded an energy intensity similar to the other fixed speed pumps (1.3 kWh/kL). The use of a pressure vessel reduced energy intensity by 30% and 32% in the two sites that were tested.

Comparison of results from sites that used rainwater for the same end uses showed a wide variation in energy intensity and water and energy consumption. Sites using rainwater for toilet flushing, laundry and outdoor use had energy intensities ranging between 0.9 – 2.3 kWh/kL. Sites using rainwater for all household end uses had energy intensities ranging between 1.4 - 3.4 kWh/kL. The differences in recorded energy intensities between these households are due not only to the different pump types used, and the presence of other system components (i.e. a pressure vessel) but also to specific end uses and water use efficiency (both efficiency of appliances and behaviour).

Using empirical data from a pump manufacturer, it can be confirmed that low flow water use events associated with end uses such as a toilet, faucet or drip will have a higher energy intensity than higher flow water use events associated with outdoor water use, showering or a bath. Using this data in the model that has been constructed for this research project, toilets and hand basin faucets were found to be the most energy intensive (around 2.8 kWh/kL) due to their nature as low flow end uses. Energy intensities for clothes washers, baths and for irrigation/outdoor use were much lower (around 0.8 kWh/kL) as these end uses are characterised by higher flow rates.

The difficulty in matching the flow rates required by end uses with a fixed speed pump was identified as the main source of pump inefficiency. End uses can range from 20 to 30 L/min for irrigation to 5 L/min or less for cistern top-up or low flow tap uses.

A breakdown of pump energy losses showed that improvements to pump design and better matching of pumps to end uses could have a significant impact on reducing pumping energy requirements.

The two variable speed pump systems that were monitored both needed calibration once installed. At both Newcastle 1 and Concord, the factory pump settings caused the pump to run almost continuously until a technician was called out to adjust the pump set pressure and pressure tolerance interval. These two pumps were the same make and very similar models, so it is difficult to say whether this is an issue with other variable speed pumps. In both cases, the adjustments reduced the energy consumption of the pump.

Comparison of theoretical and actual empirical energy intensities for systems with similar pumps and end uses found that the empirical energy intensities tended to be higher than those that were calculated using a pump model and household water data. Models used by manufacturers to determine energy consumption were found to generally underestimate the energy consumed by the pumps in practice.

Rainwater systems examined in this research project that had high energy intensity did not have high overall energy consumption because they generally also had lower water usage due to the use of efficient appliances and fixtures. In general the systems with the highest energy intensities were the most water efficient due to a combination of both appliance and behavioural efficiency of those households.

Energy intensity and overall energy consumption are affected by the following factors:

- ***System configuration*** including pump type, switching system and pressure vessel. Investigations so far indicate that a pressure vessel can reduce energy consumption if it is compatible with other system components, but may not, for example, reduce energy intensity when used in combination with an automatic switching system. Variable speed pumps may not reduce energy intensity as theory would suggest and this may be due to the fact that calibration is required on site to adjust the pump for a specific context.

- ***Types of end uses*** that are supplied by rainwater, with lower flow end uses such as toilet flushing (cistern refilling) and hand basin use contributing to higher energy intensity. Households using rainwater for all end uses tended to have higher energy intensities and this may be partly due to the greater frequency of low-flow water use events, such as hand basin use.

- ***Water use behaviour and the presence of efficient appliances*** ultimately determines overall energy consumption, as a highly water efficient household can overcome an inefficient pumping system and still have a lower overall energy consumption (e.g. Balmain or Newtown), as compared to other households with more efficient pumping systems and high water use (e.g. Padstow or Newcastle 2).

A major conclusion of this research is that there are very large potential efficiency gains that can be made in the design and operation of small pumps, with a factor of more than 20 between the theoretical minimum and the average energy intensity. The identification of the most cost-effective opportunities to reduce the energy intensity represents the most important next steps in this research.

The results of this research project have significant implications for the future of distributed water supply systems, in the following ways.

- Without attention being paid to the pump selection, pump design and rainwater system configuration the energy intensity of water supplied by rainwater systems can be higher than scheme supply in many utility areas. The typical energy intensity of water supply for the most common pump and rain switch system is approximately 1.5 kWh/kL compared to the energy intensity of mains water supply of less than 1 kWh/kL. The energy intensity of water supplied by large-scale desalination is typically greater than 4 kWh/kL at present.

- Typically the water efficiency gains associated with houses that have rainwater tanks installed, especially houses that have been subject to development consent conditions such as BASIX in NSW, will result in energy savings that far outweigh the impact of the increase in energy intensity of the rainwater tank water use.

- The systems analysed and tested in this research project, that is, rainwater systems in a single residential dwelling, represent a potentially higher energy intensity application than other future distributed systems, including collection and reuse of rainwater in a multi-residential dwelling or commercial building where higher flow rates can be maintained. This research project has also focussed on rainwater capture and reuse rather than effluent treatment and reuse, which will have different energy use characteristics and would need to be compared with the combined water supply and wastewater treatment parts of the centralised urban water cycle (Retamal et al. 2008).

- There is significant potential to reduce the energy intensity of rainwater use through improved pump sizing, pump design and rainwater tank system configuration. Potential opportunities include the use of pressure vessels, rain switch systems, variable speed pumps, overhead storage tanks and dual pump systems. The relative magnitude of the savings associated with these measures needs further investigation.

- Policies that encourage or require the installation of rainwater tank systems, such as development consent conditions and rebate programs, need to take into account the impact of these programs on the energy intensity of water supply and absolute energy use. For example, at minimum, the BASIX energy calculations should include rainwater tank pumps and some guidance or minimum standards should be set for rebates and for plumbers installing rainwater systems that support improved energy efficiency.

10.2 RESEARCH GAPS

This research project has led to a series of important conclusions that need to influence the future direction of distributed water supply systems, and specifically rainwater tank systems. The research has also led to the identification of further research gaps, including those aspects described below:

- Measuring, in real applications, the relative reduction in energy intensity and estimating the marginal increase in cost associated with the identified measures including pressure vessels, improved sizing of pumps, improved pump design, mains switching devices, variable speed pumps and header tanks.

- Improved policy and regulatory arrangements for development consent conditions (such as NSW BASIX) and rebate programs (such as the National Rainwater and Greywater Initiative) that encourage reduced energy intensity of system design. This could include guidelines, minimum performance standards and similar arrangements.

- Extending this research to the measurement of energy use in more complex configurations of distributed water systems, for example multi-residential dwellings, commercial buildings, neighbourhood systems, effluent treatment and reuse systems and stormwater capture and reuse systems.

11 REFERENCES

ABS 2004, *Household and Family Projections*, in A.B.o. Statistics (ed.)no 2001-2006, Canberra, <http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/3236.0>.

Apostolidis, N. 2003, 'Integrated Water Management–Pushing the Boundaries', *Proceedings of IWA International Conference, Efficient use and management of urban water supply,*, Tenerife, Spain, <http://www.ipwea.org.au/papers/download/Apostolidis_Nicholas.pdf>.

Bax, G. 2008, 'Staff member Apar Pumps Pty Ltd', personal communication, 2 October, 2008, Sydney.

Beal, C., Hood, B., Gardner, T., Lane, J. & Christiansen, C. 2008, 'Energy and water metabolism of a sustainable subdivision in South East Qld: a reality check', paper presented to the *ENVIRO'08*.

Britton, T., Cole, G., Stewart, R. & Wiskar, D. 2008, 'Smart Metering as a Tool for the Remote Diagnosis of Leakage in Residential Households', paper presented to the *3rd National Water Efficiency Conference, March 2008 in Conference Proceedings & Participant List, AWA, Sydney.*, Surfers Paradise, Australia.

Callaghan, B. 2008, 'Phone conversation July 31st 2008', personal communication.

Cheng, C.L. 2002, 'Study of the inter-relationship between water use and energy conservation for a building', *Energy & Buildings*, vol. 34, no. 3, pp. 261-266.

Chiu, Y.-R., Liaw, C.-H. & Chen, L.-C. 2009, 'Optimizing rainwater harvesting systems as an innovative approach to saving energy in hilly communities', *Renewable Energy*, vol. In Press, Corrected Proof.

Clearwater 2005, *Inkerman Oasis Development*, <http://www.clearwater.asn.au/stormwater_infoexchangedetails.cfm?area=true&AreaID=41&CategoryID=1&ID=566>.

Cohen, R., Nelson, B. & Wolff, G. 2004, *Energy down the drain: the hidden costs of California's water supply*, Natural Resources Defense Council and Pacific Institute, California.

Coombes, P.J. 2002, *Rainwater Tanks Revisited: New Opportunities for Urban Water Cycle Management*, University of Newcastle.

Coombes, P.J., Kuczera, G. & Kalma, J.D. 2003, 'Economic, water quantity and quality impacts from the use of a rainwater tank in the inner city', *Australian Journal of Water Resources*, vol. 7, no. 2, pp. 101-110.

Department of Planning (NSW) 2008a, *Single Dwelling Outcomes 05-08: BASIX Ongoing Monitoring Program*, NSW Government.

Department of Planning (NSW) 2008b, *Single Dwelling Outcomes 05-08: BASIX Ongoing Monitoring Program,*, NSW Government.

DEWHA 2009, *National Rainwater and Greywater Initiative: Rebates for households to install rainwater tanks or greywater systems*, Department of the Environment Water Heritage and the Arts,.

Diaper, C., Tjandraatmadja, G. & Kenway, S. 2006, *Sustainable subdivisions: Review of technologies for integrated water services (Research report)*, CRC Construction Innovation

Diaper, C., Tjandraatmadja, G. & Kenway, S. 2007, *Sustainable Subdivisions: Review of technologies for integrated water services*, CRC for Construction Innovation.

Evans, R.O.H., J.H.; Sneed, R.E. 1991, *Pumping plant performance evaluation*, , Last Electronic Revision: June 1996 (KNS) edn, vol. 452-6, no Subseries: Water & Energy Efficiency in Irrigation, AG - North Carolina Agricultural Extension Service, North Carolina State University, p. 8 p.<http://www.bae.ncsu.edu/programs/extension/evans/ag452-6.html>.

Flower, D.J.M., Mitchell, V.G. & Codner, G.P. 2007, 'The potential of water demand management strategies to reduce the greenhouse gas emissions associated with urban water systems', *1st Conference on Sustainable Urban Water Management & 9th Conference on Computing and Control in the Water Industry*, Leicester, UK, 3-5 September, 2007.

Gardner, E.A., Millar, G.E., Christiansen, C., Vieritz, A.M. & Chapman, H. 2006, 'Energy and water use at a WSUD subdivision in Brisbane, Australia', *Australian Journal of Water Resources*, vol. 10, no. 3.

Kenway, S.J., Priestley, A., Cook, S., Seo, S., Inman, M., Gregory, A. & Hall, M. 2008, *Energy use in the provision and consumption of urban water in Australia and New Zealand*, CSIRO: Water for a Healthy Country National Research Flagship.

Lance, M. 2008, 'General Manager, Engineering, Davey Water Products', personal communication, Nov. 17, 2008, Scoresby, VIC.

Melbourne Water undated, *Site 1 – Inkerman Oasis, St Kilda*, <http://www.melbournewater.com.au/content/library/wsud/case_studies/inkerman_oasis.pdf>.

Mitchell, V.G. 2006, 'Applying Integrated Urban Water Management Concepts: A Review of Australian Experience', *Environmental Management*, vol. 37, no. 5, pp. 589-605.

Naiad 2007a, *Pimpama Coomera Waterfuture Project, Gold Coast, QLD*, <http://www.naiad.net.au/?q=node/48>.

Naiad 2007b, *Silva Park, Brisbane, QLD (Payne Road)*, <http://www.naiad.net.au/?q=node/49>.

Retamal, M., White, S. & Fane, S. 2008, 'Designing for Zero Net Potable Water Use: A Case of Urban Renewal in Sydney, Australia', *Sustainable Water Management: Concepts Towards a Zero-Outflow Municipality*, vol. 3-2008, pp. 30-35.

Roberts, P. 2004, *Household Water Audit Data in the Greater Melbourne area. Data from the 2004 Residential End Use Measurement Study (REUMS).* in Y.V. Water (ed.)Melbourne, <http://www.yvw.com.au/NR/rdonlyres/983166CA-B506-4C08-8B95-5EDD378CFB53/0/REUMSReportFinal.pdf>.

Snelling, C., Simard, S., White, S. & Turner, A. 2006, *Gold Coast Water Evaluation of the Water Demand Management Program*, Institute for Sustainable Futures for Gold Coast Water and QLD EPA.

Sydney Water Corporation 2008, *Water Conservation and Recycling Implementation Report 2007- 08*.

Turner, A., White, S., Beatty, K. & Gregory, A. 2005, 'Results of the largest residential demand management program in Australia', *International Conference on the Efficient Use and Management of Urban Water*, Santiago, Chile, 15-17 March 2005.

Turner, A.J., White, S., Kazaglis, A. & Simard, S. 2007, 'Have we achieved the savings? The importance of evaluations when implementing demand management', *Water Science and Technology*, vol. 7, no. 5-6, pp. 203-210.

Veale, J. 2006, 'Clovelly House, East Sydney, New South Wales. ' *The BDP Environment Design Guide August 2006. Royal Australian Institute of Architects.*

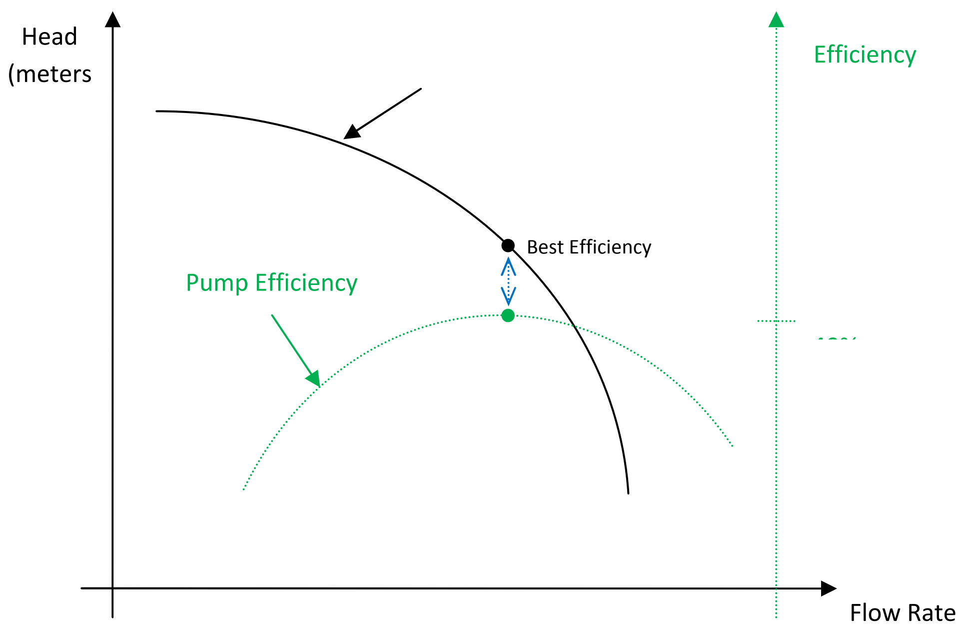
APPENDIX A: PUMP EFFICIENCY

The type of pump and the efficiency of pumps have been identified as key considerations in this research project and this is discussed in more detail here.

Brief Introduction to Applied Pump Theory (Rainwater Systems)

Modern urban rainwater systems frequently use a pump to provide water pressure for end uses. The proper design and investment in the system can minimise the energy impacts, but this requires an understanding of the behaviour of pumps. The low efficiency inherent in smaller pumps is often overlooked (Chiu et al. 2009). This is an important distinction between larger pumps such as those used for utility-scale water pumping, and the typical pumps that are deployed in small rainwater harvesting systems.

Figure A-1 Pump curve showing best efficiency point (BEP)



In most cases, head can be treated as pressure with a simple conversion factor. If only water is pumped (at or near sea level), it is safe to use a conversion of 9.8 kPa per 1 metre of water. The pump curve shown in Figure A-1 is typical for a pump and shows that the pump will supply a given rate of water for a set amount of head. If the head in the system increases, the resistance in the piping goes up and the flow rate will decrease. If the system resistance or head goes down, the flow rate will increase.

If a pump is properly chosen for an application, it will operate primarily at its Best Efficiency Point (BEP). Here, efficiency is a measure for how much of the work/energy that is put into the pump actually transfers into the work energy that is imparted to the pumped fluid. The BEP is the point at which the pump will achieve highest output for energy input. If the pump operates at either a lower or higher flow rate, it will lose a higher ratio of energy as heat and other friction losses.

For most pumping applications, the traditional type of pump selected is a single-speed pump. In this configuration, the pump is driven by a motor that runs at only one speed, and the pump will function in a manner similar to the pump curve in Figure A-1. Ideally, the system will be designed to achieve optimum energy efficiency by ensuring that the pump operates at the BEP.

Large Pumps vs. Small Pumps

For small pumps (less than 1 kW) an efficiency of about 40–50% (Bax 2008) may be assumed at the best efficiency point, although larger industrial pumps may achieve efficiencies in the range of 75–85% (Evans 1991). There is a similar disparity in motor efficiencies. A typical small motor will operate at about 70% efficiency (Bax 2008) and a larger motor will be closer to 90% efficient in converting electrical energy to rotation energy (Evans 1991). This creates a net efficiency (from electricity input to pumped fluid output) of around 30% for a small pump, compared to closer to 68–79% (Evans 1991) for large industrial pumps. From this discussion, it may appear that larger pumps are preferred to improve efficiency, but it is worth noting that there is substantial energy required to deliver water longer distances from a centralised location.

The efficiency considerations for small pumps are often overlooked, for example in (Cheng 2002) which was a study of the interrelationship between water use and energy use for a high-rise building. In this study all pumps were assumed to be for multi-unit dwellings, so the pumps will be larger and can achieve higher efficiencies.

The levels of efficiency are also influenced by the manufacturing techniques, design choices, etc. Smaller pumps tend to use less expensive materials and have less stringent tolerance requirements to reduce capital cost.

APPENDIX B: BREAKDOWN OF PUMP LOSSES

The following chart was derived from a combination of data from the literature and engineering judgement. The amount of water that is supplied by a rainwater tank will vary significantly based on rainfall, roof area, tank size and choice of end uses that are supplied. For the purpose of this research project, and to ground the results in actual practice, an estimate of water supplied by a rainwater tank in a BASIX-compliant Sydney based household was used.

The water saved annually in a house that satisfies the BASIX water target was calculated by taking the difference in water consumption per person between a BASIX house and a non-BASIX house and then assuming that half of the 40% BASIX water savings were obtained from the rainwater tank (20%) and the other half by efficiency measures (20%).

The BASIX-compliant house is assumed to use 135 L/person/day and the average (non-BASIX) house 237 L/person/day (Department of Planning (NSW) 2008b). This yields the difference between the amount of water saved in a non-BASIX house and a BASIX house. The water savings are achieved through a combination of efficiency measures, e.g. water-efficient showerheads, and through source substitution, e.g. use of rainwater instead of mains water. The relative attributions of savings to these two measures are estimates. Since approximately 95% of all BASIX certificates chose to have a rainwater tank for water source substitution (Department of Planning (NSW) 2008b) the 50% split was assumed to be an appropriate approximation for rainwater tank water consumption. To achieve expected water consumption for an average household, the rainwater usage per resident was multiplied by the average occupancy, 2.6 resident/household (ABS 2004). Therefore, the typical rainwater used in a BASIX house can be taken to be:

$$V_{rainwater/household} = \left(V_{Non-BASIX/person} - V_{BASIX/person}\right) \cdot P_{rainwater} \cdot N_{persons/household}$$

$$V_{rainwater/household} = (237\frac{L}{person \cdot day} - 135\frac{L}{person \cdot day}) \cdot 50\% \cdot 2.6\frac{persons}{household}$$

$$V_{rainwater/household} = 146L/(household \cdot day)$$

Or, equivalently, this can be converted to annual household usage, 53 kL/(household·year).

From this result it is possible to calculate the expected annual energy required to deliver rainwater in a BASIX house. The energy was calculated by multiplying the approximate current energy intensity determined in this report, roughly 1.5 kWh/kL, by the estimate of rainwater used in a BASIX house. This yields 53 kL/(household·year) x 1.5 kWh/kL≈ 80 kWh/(household·year). From this calculation, it can be seen that approximately 80 kWh is required to deliver rainwater in an average BASIX home.

For comparison, it is interesting to calculate the theoretical minimum amount of energy to deliver the same amount of rainwater. From basic physics, the energy required to deliver 53 kL of water is calculated as:

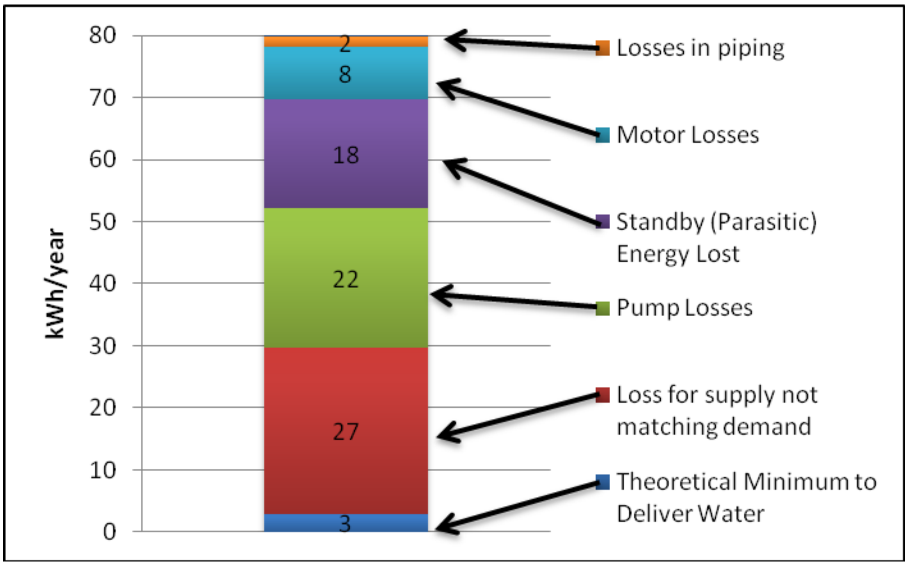
$$Energy = \rho_{H_2O} gHV \cdot (Factors_{conversion})$$

$$Energy = 1000\frac{kg}{m^3} \cdot 9.81\frac{m}{\sec^2} \cdot 20m_{H_2O} \cdot 53\frac{kL}{year} \cdot \left(\frac{1m^3}{1kL} \cdot \frac{1J}{1\frac{kg \cdot m^2}{s^2}} \cdot \frac{3.6kWh}{1J} \right),$$

$$Energy = 2.9kWh / year$$

where ρ_{H2O} = 1000kg/m^3 is the density of water at room temperature and g = 9.81 m/sec^2 is the gravitational constant. H = 20 meters of water is the standard minimum acceptable water pressure for many utilities. Any excess pressure beyond this is not necessary for standard residential water systems. Therefore, for an average BASIX-compliant household with a typical rainwater system, 2.9 kWh is the theoretical minimum energy to supply rainwater for one year. The remaining energy is lost through inefficiencies in system design. These losses are shown in Figure B-1.

Figure B-1 Energy losses associated with a household rainwater pump



The energy losses due to standby (parasitic) power were calculated by assuming that the pump system draws 2 watts at all times, even when the pump is not operating. This is from electrical losses within the power block, power to the control and sensor systems. This value approximately corresponds to the constant power draw seen in the test data for single-speed pumps.

The losses in piping were estimated by assuming that there was approximately a 5% loss of energy due to friction in the piping system. Since water is incompressible, the piping loss corresponds to the loss in pressure from the inlet of the piping system to the outlet.

Motor losses were calculated by assuming that the motors are only 75% efficient at converting supplied electrical energy to rotational energy to turn the pump.

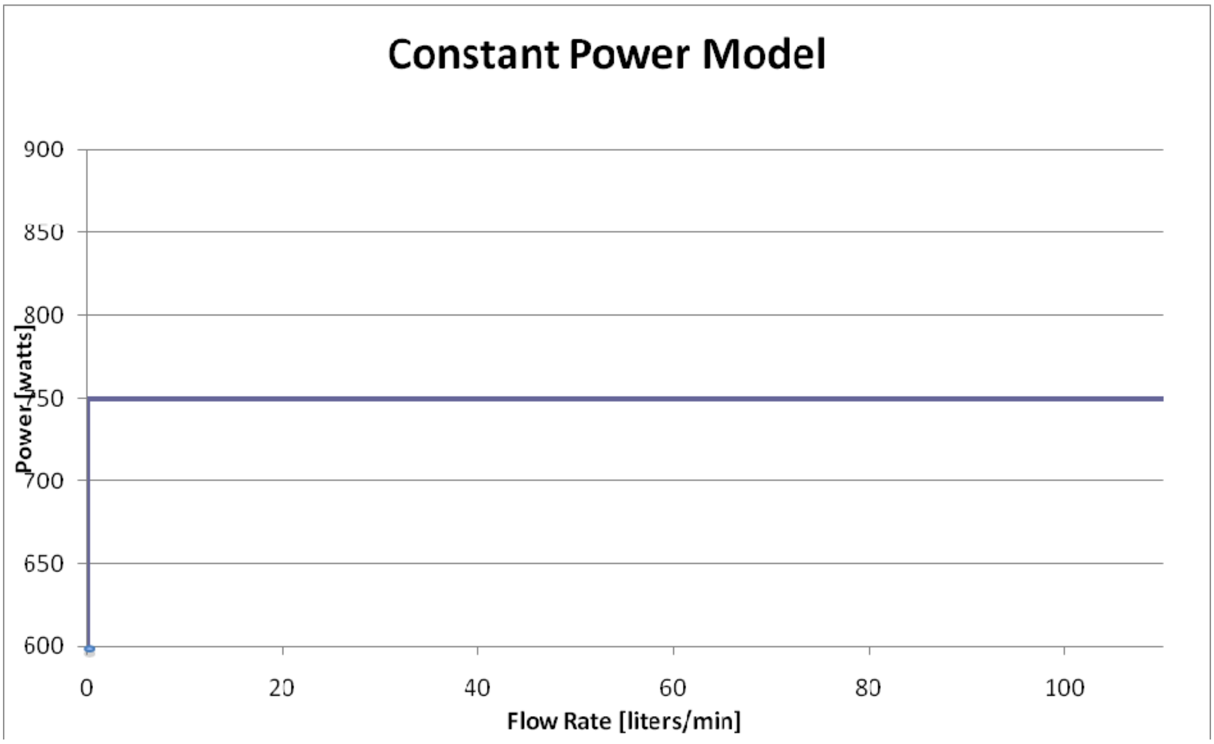
Pump losses were calculated by assuming the efficiency of the pump to convert the rotational energy from the motor to pumped water is approximately 33%. This low efficiency is due to the aggregation of multiple sources of data and engineering judgment, and reflects the poor efficiency of small pumps (see Appendix A for a discussion on large vs. small pumps).

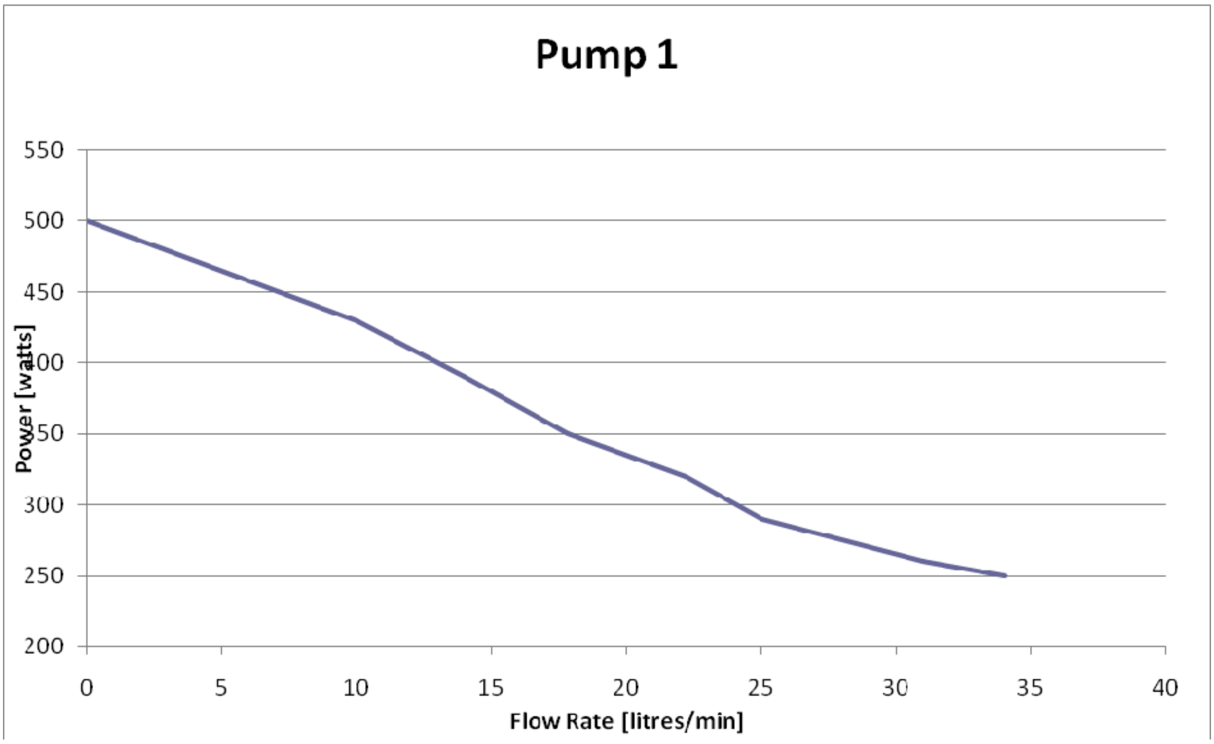
The loss for supply matching demand is calculated by observing that most rainwater pumps are designed to perform optimally at flow rates between 20 and 30 lpm (litre/minute); the best efficiency point (BEP) is in the range 20 to 30 lpm. Although this may be reasonably well matched to a high-performance irrigation system, it is not well suited for most indoor uses. Assuming the typical toilet and clothes washer use around 5 lpm, and that the power curve for a small pump is relatively flat for all flow rates (see constant power model pump, Figure 6-1), the pump operates at approximately 5 lpm/ 25 lpm = 80% below optimal efficiency.

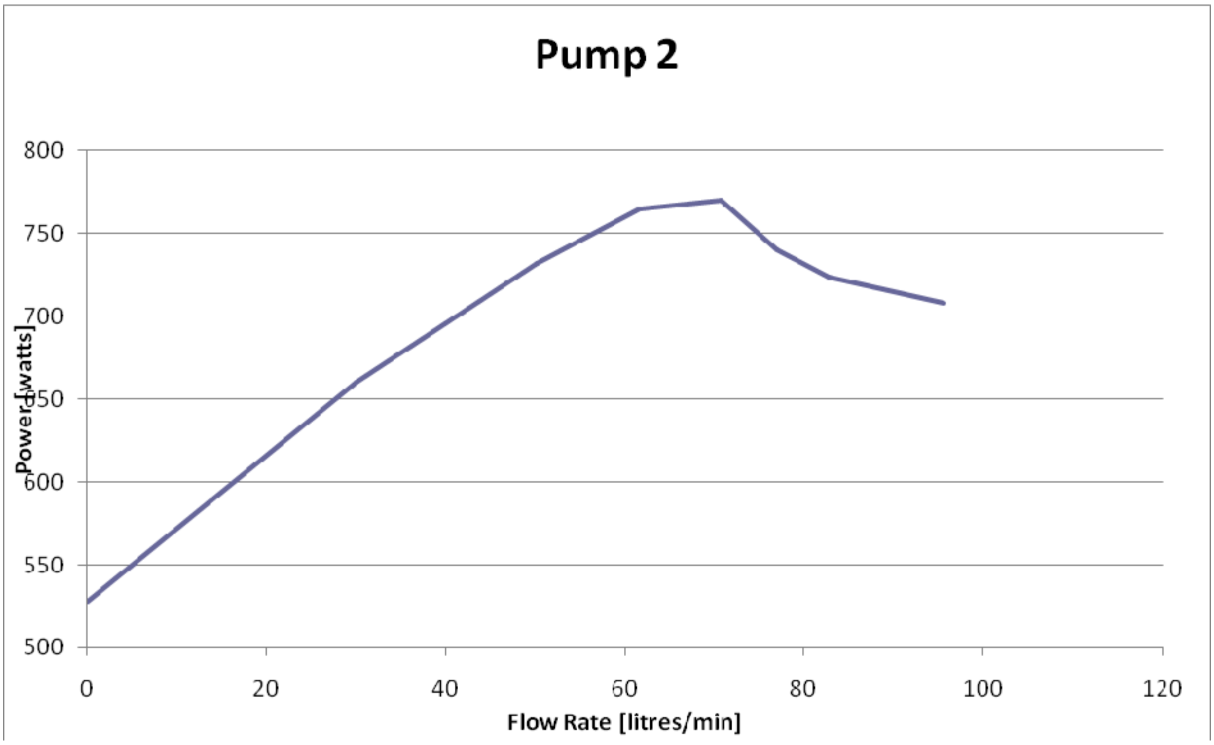
Aggregating the various efficiencies/losses and calculating the relative contribution of each loss to the total loss yields the net efficiencies as seen in Figure B-1.

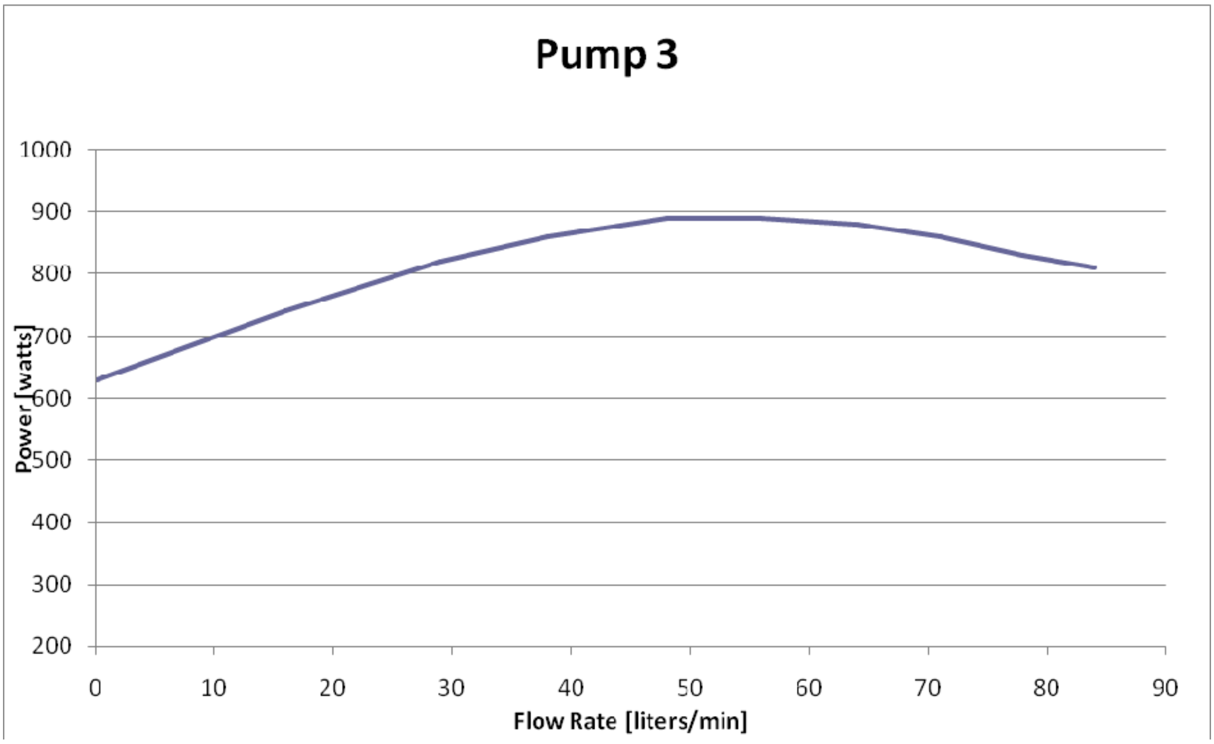
As a final note, the assumptions used in the calculations are a first-order approximation. They are selected to illustrate simply and directly where the energy inefficiencies in a pumped rainwater system occur. Specific systems may have substantially different energy and efficiency profiles, but the numbers used provide a broad snapshot of the pumps currently used for rainwater systems.

APPENDIX C: PUMP POWER CURVES USED IN THEORETICAL MODELLING






Pump 2
800
750
700
650
600
550
500
Power [watts]
0
20
40
60
80
100
120
Flow Rate [litres/min]


Pump 3
1000
900
800
700
600
500
400
300
200
Power [watts]
0
10
20
30
40
50
60
70
80
90
Flow Rate [liters/min]