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Performance Assessment of a Greywater Recycling Experimental Test Rig

This thesis is submitted to the School of Engineering and Information Technology, Murdoch University, in partial fulfilment of the requirements for the degree of Bachelor of Engineering.

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ABSTRACT

In the past decade, the world has witnessed a huge expansion at a progressive rate of its population, its urban density, and its water use. As the world's population steadily grows, so too does global understanding of finite resources, with society increasingly looking towards technology to facilitate the epic task of managing natural resource usage. This increasing pressure on finite water resources clearly manifests itself in today's context of increasing water restrictions and rising water costs.

In order to meet future water demands, it is essential that potable water usage levels be reduced to a sustainable rate. To achieve this goal, it is necessary to explore viable alternative sources of water that offer the potential to improve water use and significantly contribute to the overall reduction in potable water consumption. One such source is greywater (GW). GW reuse systems are a common feature of many households in other developed countries, but the benefits of GW reuse has yet to be properly demonstrated in Australia.

Water Corporation consumption data shows that nearly 40% of Western Australian households total water consumption is used on gardens and landscapes. As the average Perth household currently consumes around 254 kL of scheme water per year, implementing greywater reuse technology could potentially reduce the average household water bill by 30%, providing a significant cost saving.

However, there is a recognised gap in available residential water use data related to GW generation and reuse where it occurs. Existing water meter technology performs poorly in the task of accurately measuring GW volumetric discharge. The reason for this is the design of the traditional water meter and its inability to provide accurate readings over time with GW due to clogging. This clogging can occur as a result of the presence of cleaning chemicals and suspended solid and foreign matter found in GW from a domestic environment.

This thesis will investigate whether an alternative way to accurately measure household GW being captured and discharged to the garden can be developed from the energy consumption of the pump in a greywater recycling system (GWRS). The results would provide an accurate means of evaluating the potential financial savings of greywater reuse systems.

ACKNOWLEDGMENTS

I would like to thank my supervisors Dr Martin Anda and Dr Stewart Dallas, and also thank Sam Milani for his assistance and technical help by way of Bernard Devera. I am extremely thankful for all of David Goldfields' technical assistance regarding the HOBO monitoring equipment in the test rig.

Finally, and most importantly, to my family and friends for continuously providing me with love and support; their patience throughout my studies was greatly appreciated. Unless otherwise indicated, all photographs, illustrations, charts, and diagrams included in this thesis report were created by the author Kathleen Byrt

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LIST OF ABBREVIATIONS & SYMBOLS

ABS:	Australian Bureau of Statistics
AC:	Alternating Current
AMI:	Advanced Metering Infrastructure
AMR:	Automatic Meter Reading
AWWS:	Advanced Wastewater Systems
BAU:	Business-as-usual
CoP:	The Code of Practice for the Reuse of Greywater in WA
CSV:	Comma Separated Values (a type of flat text file)
CT:	Current Transformer
DoH:	Department of Health
DoW:	Department of Water
ETC:	Environmental Technology Centre
GDD:	Greywater Diversion Device
GDS:	Greywater Diversion System
GFPS-PP:	GreyFlow Pre-Lay Stage (PS) Plug & Play (also GreyFlow)
GW:	Greywater
GWIG:	Greywater and Wastewater Industry Group
GWRS:	Greywater Recycling System
GTS:	Greywater Treatment System
HOBO:	Onset HOBO– U30 data logger
IC:	Integrated Circuit
IWSS:	Integrated Water Supply System
LDPE:	Low-density polyethylene
LIR:	Loading Infiltration Rate
NRW:	Non-Revenue Water
NWC:	National Water Commission
OWRM:	Optimal Water Resources Mix project- SA water end use study
PD:	Positive Displacement
PDWUS:	Perth Domestic Water Use Study 2008-09
PU:	Polyurethane foam
SEQ:	South East Queensland
SEQREUS:	SEQ Residential End Use Study
SMEC:	Snowy Mountains Engineering Corporation
WA:	Western Australia
WBWC:	Wild Bay Water Corporation
WCorp:	Water Corporation
WDM:	Water Demand Management
WELS:	Water Efficient Labelling Scheme
WSAA:	Water Services Association of Australia
UWSRA:	Urban Water Security Research Alliance

Units

hh:	Average size household represents 2.6 persons
GL:	Gigalitre
kL:	Kilolitre
L/hh/d:	Litres per household per day
L/p/d:	Litres per person per day

LCD:	Litres per capita per day
RMS:	Root mean square – power measurement in micro volts (mV)

CHAPTER 1

1 INTRODUCTION

1.1 Background and Scope

Despite having long been recognised as the world's driest populated continent (SoE, 2006), Australia has one of the greatest per capita water usage rates in the world and, according to international standards, is currently listed within the top 20 highest water-consuming nations (Hoekstra, 2007).

As Australia's population grows amid varying climatic conditions, meeting future water demands will become a challenge. This increasing pressure on finite water resources clearly manifests itself in today's context of increasing water restrictions and rising water costs.

In order to meet future demands, it is essential that potable water usage levels be reduced to a sustainable consumptive rate. To achieve this goal, it is necessary to explore alternative sources of water that offer the potential to improve efficient water use and significantly contribute to the overall reduction in potable water consumption, such as (GW). Despite being a common alternative in Europe, the use of GW systems is yet to be fully accepted in Australia.

Since 2008, Australian organisations have endeavoured to reduce the country's total water usage level, resulting in the national per capita average currently estimated at 80 kL per annum (ABS, 2014). However, this average is not a true representation of all states and territories, as Western Australia currently is well above the national average at 132 kL per person per year (WCorp, 2015).

Over the last seven years, we have seen a reduction of 1.2% in the National per capita average being achieved, as represented in Figure 1. In comparison, the average Perth household has reduced its consumption by 8.3% for the same time period, currently consuming 254 kL of scheme water per year, of which nearly 40% is used on gardens and landscapes. A further reduction can be achieved by reusing a home's GW onsite; this has the potential to significantly reduce household total water consumption by around 30% per year.

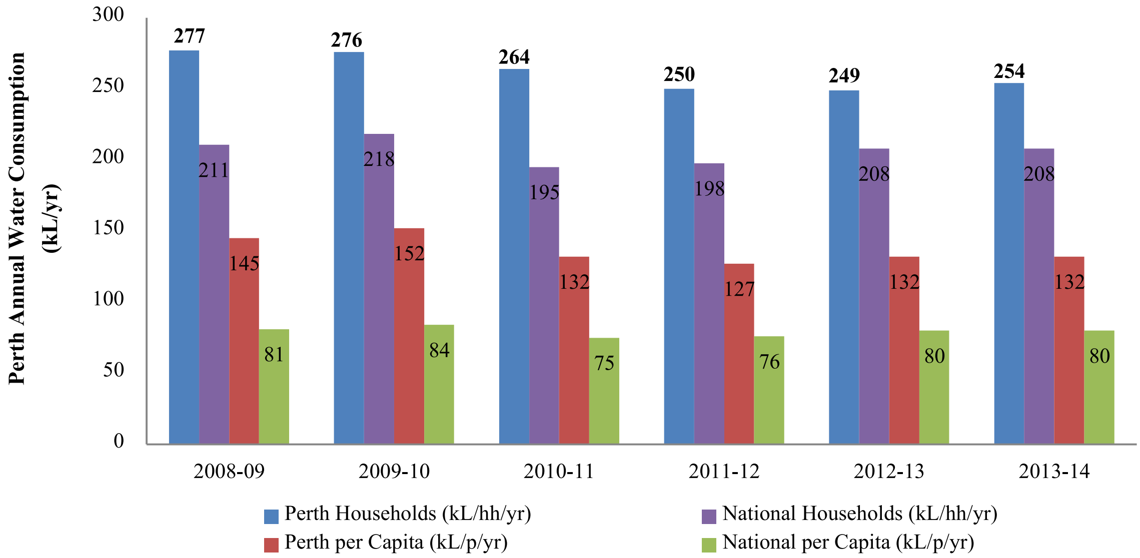


Figure 1: Annual water consumption over the last seven years.

Specifically, GDS reuses domestic GW within 24 hours for onsite use by directly diverting the filtered wastewater through a drip irrigation network. The reuse of GW like this can noticeably increase water-use efficiency and decrease the overall water footprint of a household.

To help address future water demands, Water Corporation (Water Forever) has set a water efficiency target of 15% reduction of Western Australia's total household water consumption to be achieved by 2030, in addition to increasing the current proportion of wastewater that is currently recycled from 13.5% to 30% (W.Corp, 2009). However, in order for these targets to be met, a shift in the public's perception and understanding of the benefits of reusing GW is essential (Evans, 2009).

Unfortunately, data around actual GW volumes produced per household is currently limited to traditional water meters. A traditional water meter's ability to accurately measure GW volumes is greatly diminished over time due to clogging as a result of either the presence of cleaning chemicals, suspended solids and foreign matter found in a domestic environment. However, due to time constraints as a result of injury the original approach designed to investigate clogging was no longer practical within the time remaining, resulting in a less involved version to be used which yielded no result.

Reliable quantitative information on water and energy usage in the field of greywater recycling does not currently exist on a large domestic scale. The primary focus of this thesis is to establish a relationship between a pump's discharge volume and the energy it uses to perform this task. Developing an understanding of the correlation between these factors will provide an accurate measure of potential cost savings and render inaccurate traditional flow meters redundant.

An experimental test rig was assessed under various performance conditions to ascertain a clean baseline flow in order to provide consistent results for the research. The objective of the research was to collect data based on water and energy consumption when treating GW for reuse in the domestic environment.

This thesis will investigate whether an alternative way to accurately measure a household volumetric GW discharge can be developed using the energy consumption of a GWRS pump to accurately measure the volumetric flow. The results would provide an accurate means in evaluating the potential financial savings of greywater reuse systems.

1.2 Greywater and its Reuse

Domestic GW is defined as all the reusable wastewater generated from any non-toilet plumbed sources from the kitchen, laundry, and bathroom within the home, excluding wastewater from the toilet that is deemed unusable for reuse on a localised scale and is classified as blackwater (or sewerage). GW refers specifically to wastewater that originates from the source relatively 'clean'. This includes wastewater from washing machines, utility tubs, showers, baths, and hand basins (GWIG, 2013).

The main difference between GW and blackwater is the elevated levels of organic matter and faecal coliforms (EMRC, 2011).
Kitchen-sourced wastewater is often referred to as blackwater on account of the high levels of fats, oils, and detergents wastewater from kitchen sinks and dish washers, making it ineligible for reuse unless treated to high standard by an approved greywater treatment system first (DoH, 2010).

Typically, there are only two streams of GW generated from a house: (1) water sourced from the bathroom and laundry and (2) water from the kitchen (provided that the level of treatment kitchen GW receives is adequate to meeting health stands and council approval). A comparative analysis of available past residential water end-use studies (RWEUS) was done in order to calculate a more up-to-date percentage breakdown of GW volumes produced from the bathroom and laundry.

Greywater Diversion System

The concept that GW can be recycled as a sustainable water source (Figure 2) is an idea shared by many, (E.Friedler, et al., 2012) provided that the treatment meets Department of Health regulations (DoH, 2010).

According to the Department of Health's (DoH) 2010 code of practice (CoP), for reuse of GW in Western Australia, GWRS are classes depending on the level of onsite treatment that it provides: (1) Greywater Diversion Device (GDD) and (2) Greywater Treatment System (GTS).

All GWRS must be supplied by an approved WA company subject to local council approvable prior to installation. WA currently has nine approved GDD manufactures in WA, current list refer to Appendix A.

GDD can be further subdivided into gravity-operated GDD and pump-operated GDD (EMRC, 2011), as follows:

1. The gravity GDD has a manual switch directly diverting treated water to a sub-surface garden irrigation system.
2. The pump GDD incorporates a surge tank and a pump to collect and distribute the GW to the sub-surface garden irrigation system.

The GTS is different to GDD: it incorporates disinfection of the GW after it is collected to produce a higher quality of water fit for surface irrigation and other cold water reuse applications subject to DoH approval (EMRC, 2011).

This thesis will examine only the pump-operated GDD, specifically Advanced Wastewater Systems (AWWS) GreyFlow PS Plug & Play (GFPS-PP) domestic GDD pictured below in Figure 2 centre.

Figure 2: Greywater diversion system- general overview.

1.3 PROJECT HISTORY

In 2014, Doctors Martin Anda, Linda Li, and Stewart Dallas secured funding to design and build a GWR test rig. The rig was commissioned in 2014 under a joint venture partnership between Murdoch University and the Greywater and Wastewater Industry Group (GWIG).

The intention was to use the GWR test rig as a teaching tool to demonstrate the hydraulic principles of water recycling systems and to assist students conducting research trials for their final year thesis.

Implementation of the test rig was setup as a vacation project for environmental engineering student's Ashwin Nayak pictured in Figure 3. Construction of the rig was originally to be completed by the end of January 2015 by Murdoch University's lab technicians. However, due to a schedule conflict, the rig's build date was postponed. Instead, Sam Milani, the owner of AWWS, was approached about assembling the test rig at his warehouse in Malaga. The test rig was built one week later and transported to Murdoch University where is currently resides at Murdoch University's Environmental Technology Centre (ETC);

Final modification to the rig saw the addition of a reflux valve, a data-logger, and a demonstration "demo" control chip for a GDD pump; the project was completed in February 2015.

Figure 3: Photograph of the test rig during construction (Photo by Ashwin, 2015)

1.4 Aims & Objectives

The primary aim of this thesis is to examine the operating behaviour of the experimental test rig and provide detailed information on the performance of the GFPS-PP system (or G-Flow for short). Using the results, this thesis then evaluates whether the energy consumption of a GDS pump could be used to accurately determine the volume of GW being discharged, thereby removing the need for traditional and inaccurate water meters.

The main objective of this project was to establish an accurate water and energy use baseline required for comparison. The second objective was to monitor the effects associated with filter clogging and time-delay configuration.

Project-Specific Objectives

To achieve the projects aims, the specific objectives were developed:

1. Collate baseline water and energy use data to evaluate the impact of filter loading on pump performance and energy consumption. Conduct baseline trial using both time-delay control chips.
2. Undertake a comparative analysis of each flowrate's cycle-set flow patterns. Identify any changes to the total volume of water captured or discharged by the system or variation in energy consumption.
3. Determine what effect different time-delays have on total energy efficiency and what effect having an active water supply during backwash.
4. Determine if a relationship between volumetric flowrate and power consumption exists and evaluate whether it could be used as a surrogate to traditional PD flow meter data collection methods.
5. Investigate alternative metering technology for the purpose of increasing GW monitoring accuracy and possible future inclusion in end-use studies.
6. Analyse the system's response to decreased filter permeability and its effect on flowrate, captured volume, and energy use. Determine whether the pump's energy demand fluctuates.
7. Calculate the potential financial benefits associated with adopting the GDD system, including comparing the cost of paying for potable quality water against the indirect cost of the reuse of domestic GW associated with the energy requirements of daily pumping and supporting electronic monitoring devices. The probability of a shift in unit tariff bracket resulting in paying *less* for water and *more* per unit for electricity due to the increase in energy consumption must also be taken into account.

The work to achieve these specific objectives is detailed in Chapter 3 (Materials & Methods).

1.5 Thesis Layout

This thesis contains five chapters representing the investigative performance analysis of the GWR test rig at the ETC. After the first introductory chapter, the reminder of this thesis is organised as follows: **Chapter 2** introduces a background and literature review of different smart meter technologies and GW reuse technologies for potential cost/environmental benefits, domestically and globally – highlighting the current knowledge gaps in accurate GW end-use data. **Chapter 3** describes the test rigs design, setup, and data collection and analysis procedures. **Chapter 4** presents the performance analysis and discusses the results of the experimental trials. C**hapter 5** presents the conclusion highlighting all key findings and recommendations for future research using the test rig.

Chapter 2

2 LITERATURE REVIEW

This chapter aims to provide an analytical review of the current literature relating to GW reuse and its potential contribution in addressing future water demands. This literature review is designed to provide a detailed background on current and future global water demands, looking at domestic water monitoring technology, specifically smart metering technologies that aid quantifying residential water end uses.

This is followed by an investigation of factors that influence the amount of quantitative GW end-use data, along with a discussion of common technical issues inhibiting water metering and concluding with an analysis of smart meters and digital monitoring systems.

The points below highlight the core areas affecting GW adaption in mainstream life.

Barriers preventing credible GW data:

- Deficiency in the amount of end-use research data directly relating to the volume of GW available as a result of a water meter's diminished capacity to provide accuracy when used to monitor GW.
- Other technical issues including filter clogging and pump inefficiency which are direct contributors to poor data retrieval rates and a lack of system acceptance.

An investigation of recent residential water end-use studies, evaluating:

- Data collection methods used
- Level of accuracy in research results
- Smart meters and their potential application.

2.1 Water Meters

Flow measurement is concerned with how much water is being consumed and how much is being produced. As bulk flow increases, it becomes progressively more difficult to accurately manage and record a fluid's volumetric flow manually, making it necessary to develop a way of metering flow.

In 1738, Swiss physicist Daniel Bernoulli produced an equation showing that an increase in the velocity of a flowing fluid increases its kinetic energy while decreasing its static energy. It is this 'Bernoulli Equation' that forms the basis of today's differential pressure flow measurement. The invention of the oscillating piston by James Watt in 1782 later allowed Sir William Siemen to develop his "fluid meter" in 1852, which is recognised today as the world's first water metering device.

Bernoulli Formula: $$P + \frac{1}{2}\rho u^2 + \rho g h = const$$ Eq [1]

Water meters can be divided into four distinctive operating principles depending on how they measure the flow of fluid, including differential pressure, mechanical, electronic, and mass flow meters. Regardless of the type, the most important aspect of a water meter is its ability to register water consumption accurately for financial revenue.

Water utilities rely heavily on residential water meters as a means of determining a property's water usage. Readings are taken from the master meter six times a year, and consumers are billed quarterly for kilolitres of water used. Domestic meters in Australia register and record water usage in cubic metres, displaying the accumulative total directly by way of a digital (electronic) or six-digit sealed mechanical totalizer depicted in Figure 4 below. The first six digits represent in kilolitres the accumulative total water that has passed through the meter to date, and the remaining three red digits represent litre increments in descending order from left to right of 100L, 10L, and 1L, with line augmentation of 0.1L increments.

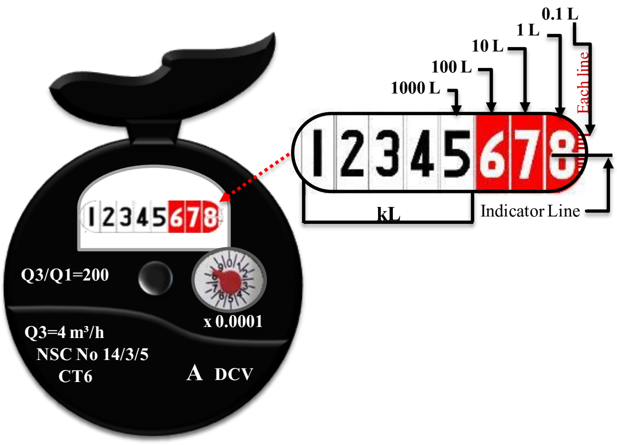


Figure 4: Domestic water meter with instantaneous six-digit sealed totalizer

The Department of Water does not specify a preferred type, model, or manufacturer of water meter, only that it must adhere to the conditions set out under the Rights in Water and Irrigation (Approved Meters) Order of 2009 (DoW, 2009). This is due to the fact that domestic water meter selection is based on a provincial fit-for-purpose rule, relating to water quality and local environmental condition.

Meter selection depends on various factors that affect operational ability, including fluid type, flow measurement method, accuracy requirements, and type of end-use and required flow rates desired. The majority of domestic water meters are either a type of positive displacement (PD) or velocity meter. Common displacement meters include oscillating piston and nutating disc (Wobbler) meters, while velocity-based meters include turbine, propeller, and single/multi-jet meters.

A positive displacement water meter directly measures a known volume of water as it flows through the device. By separating defined volumes of water for each rotation and totalising the discrete number of packages exiting the meter, the total volume passed in a given time is provided. This makes PD meters highly accurate over a wide range of flow rates, and ideally suited for monitoring potable water consumption.

Velocity meters use the angular velocity of the rotor, proportional to the velocity of the fluid moving through the meter's specific volume, to measure flow, and are capable of measuring high flow and converting it to units of volume.

The water meter of importance to this thesis is the standard 20mm diameter Elster V100 Volumetric (PD) Rotary Piston water meter shown in Figure 5 [a] and [b], which illustrates the basic design layout of an oscillating or rotating piston meter.

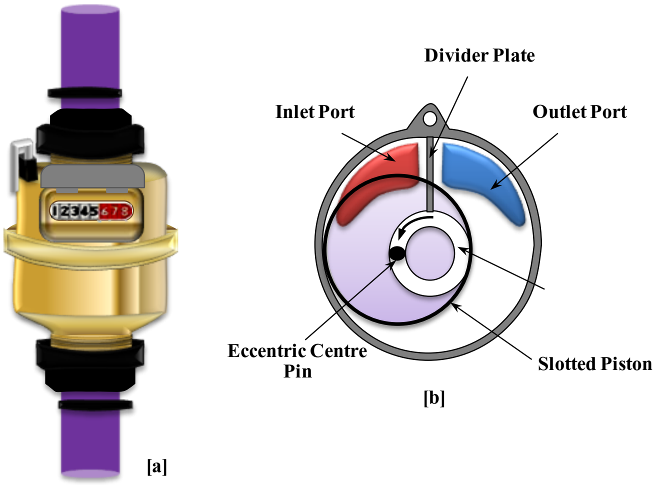


Figure 5: [a] Elster V100 PD water meter and [b] Basic layout of rotating piston meter.

Piston meters have a piston that oscillates back and forth as water flows through. A known volume of water is measured for each rotation, and the motion is transmitted to a register through an arrangement of magnetic drive and gear assembly. A more comprehensive description of the Elster V100 PD water meter is provided in Section 3.3 (Greywater Diversion Subsystem).

2.2 Problems of Accuracy

Regardless of type, all water meters have limitations and are not capable of recording an exact amount of water consumed (Arregui et al, 2005). Furthermore, there are reasons for inaccuracy not relating to the meter itself, as discussed below.

2.2.1 Consumption Volume and Meter Age

The majority of residential meters are of the positive displacement type, which, although considered the most reliable of meters, almost always slow down when they are worn or encrusted with minerals or debris (Arregui, et al., 2005), therefore becoming less accurate as they age. Other factors that affect a water meter's ability to produce accurate readings – like improper mounting position, flow distortion, or changes in the environmental working conditions – will not necessarily be the same for all water meters.

Each utility has a unique set of water usage patterns and environmental conditions which impact the degradation and accuracy of their various water meters. Intermittent supply or sudden changes in pressure can damage meters, and suspended particles and calcium deposits can reduce the capacity of measuring chambers, thus reducing the constant volume of water measured. All PD meters therefore require clean fluid at a filtration level of 100μm.

The rate and degree of wear and tear seems to be directly related to the volume of water consumed and recorded by the meter. It is therefore cumulative flow, rather than time, that affects meter accuracy, and can result in the under-registering of consumption. A meter's performance diminishes with high error variability at low flow rates, as "the wear and tear of the moving parts tends to increase the friction torque on the sensing element in any instrument increasing the error at low flows" (Arregui et al, 2005, p. 3). Other causes of meter failing include turbine high flow, turbine breakage and uncoupling of the totaliser.

2.2.2 Meter Maintenance

Residential meters should be checked, cleaned and calibrated every seven to ten years (Davis, 2005) or as indicated by the state's primacy agency. If adverse conditions such as high concentrations of dissolved minerals or large flows are encountered, meters will require more frequent attention. Testing and maintenance of the meters depends, therefore, on the quality and quantity of water being measured (Arregui, et al., 2007). Maintenance requirements will also vary depending upon the material used in the meter components. (Arregui, 2003)

3.2 Filtration

Filtration is very important unit operation widely used in 'cleaning' process, where separation of solids from dirty fluids is perform to achieve a desired level of purification (Eker, et al., 2013). Just how clean is dependent on the contamination level of the wastewater to begin with, followed by what method of filtration and filter media is used.

There are three filtration methods: (1) Mechanical, (2) Biological, and (3) Chemical. Mechanical (or particle) filtration, as the sole treatment process, is really only used in true GDD. The filtration of solid particles and contaminants present in wastewater (which originate from household daily actives) is paramount to the operation of a GDD. Typically, GDD use synthetic media polymers like polyurethane or ceramic foam to remove particles as they pass through the filter medium, though filters can be any porous material such as paper, bark, cloth, and sand (Dalahmeh, et al., 2012).

For the purposes of this thesis, only mechanical (solid-liquid) filtration processes will be examined, focusing on the 'filter cake' clogging phenomena common in GDD, while evaluating what affect this has on the systems energy demand.

Filtration in its simplest form is the separation of solid particles from fluids in suspension, by interposing a permeable filter medium(membrane) which only the fluid is capable of passing through it. As suspended particles become trapped, the fluid permeability of the medium gradually decreases and eventually the build up of suspended particles on the surface forms a thick layer known as a filter cake, while the fluid that has successfully passed through the filter is called filtrate, as illustrated by Figure 6.

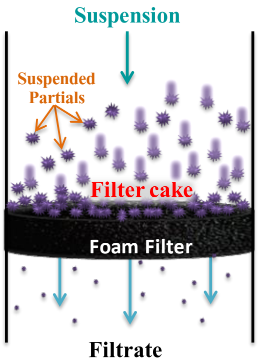


Figure 6: Diagram of simple filtration with residue deposit build-up.

Filter media is said to be anything that changes the quality of water flowing through it by acting as a substrate for physical filtration. The filter medium properties such as porosity, particle size, structure and distribution enhances filtering efficiency by increasing the available filter surface area for trapping suspended particles (Redner & Datta, 2000).

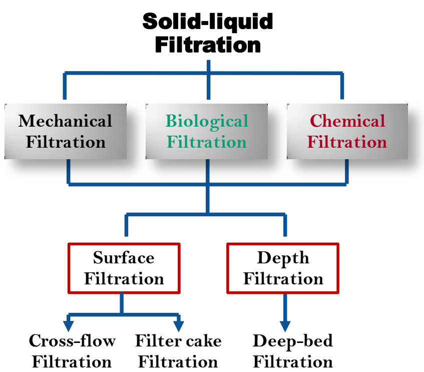
Filter media can generally be differentiate into two categories depending on where particle collection takes place. Surface filters as the name suggests collect particles mainly on their surface where the build-up of particles over time forms thick cake layer, that serves to aid filtration to a point, until it doesn't. Surface filtration is most commonly applied to low concentrations of particles in wastewater (i.e greywater) to reduce particle concentrations to very low levels before dispersing it to the garden. Whereas depth filters collect particles through the entire filter media.

SURFACE FILTRATION

Surface filtration traps contaminants larger than the pore size on the top surface of the media, while contaminants smaller than the pore size may pass through the filter (Bredin, 2012). Mechanisms such as bridging may capture some of the particles smaller than the pore size on the filter surface. These filters are generally polymeric films approximately 120 nm thick with a narrow pore size distribution. Examples are membrane filters and clothes dryer filter.

DEPTH FILTRATION

The process of depth filtration allows particles to penetrate into the filter media and be captured throughout the depth of the filter media and on the surface of the media. Depth filters are composed of random mats of metallic, polymeric, or inorganic materials. These filters have broad pore size distribution. Examples are fibrous filters and furnace filters.



Solid-liquid filtration can be classified into three categories as follows: (1) deep-bed filtration, (2) cross-flow filtration, and (3) cake filtration (Figure 7).

Deep-bed filtration works by separating the suspended partials from the fluid as it passes through the filter, depositing particles throughout the filter medium. A prime example is the sand filter. The filtration mechanism in cross flow has the fluid flowing parallel to the filters, allowing only clean filtrate to be discharged. Lastly is cake filtration, which has two types of cake filtration processes: (1) constant rate filtration and (2) constant pressure filtration. This thesis will investigate solid-liquid constant pressure cake filtration using the GWR test rig located at the ETC.

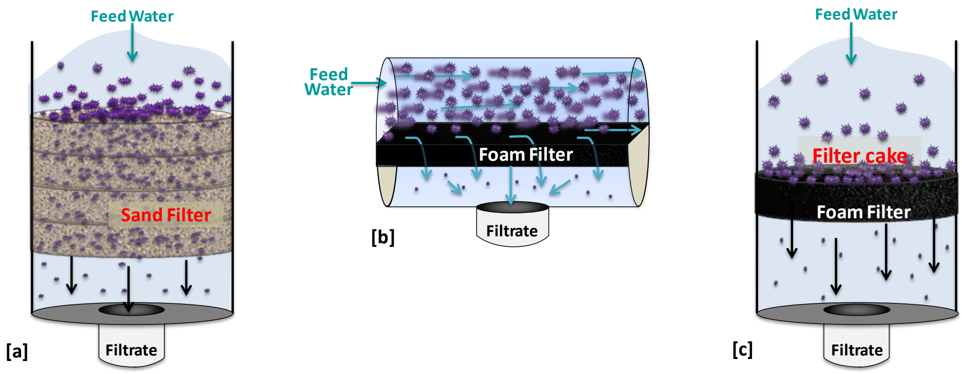


Figure 7: Depth Filtration [a], and Surface Filtration [b].

Surface and Depth Combined

➔ **Fibrous Filters**

Fibrous filters initially behave as depth filters when new; however, with increasing operation, they will eventually transition to surface filtration, where the particles collected on the filter surface form a cake demonstrated in Figure 8.

Particles at this stage are mainly captured by the highly porous filter cake, and not by the filter fibres themselves. Contaminant particles range from 0.1 nm to 100 nm and the most penetrating particle range is between 100nm and 500 nm. Fibrous filters are commonly used medium for particles in size ranging from about 0.2 to 500 microns.

Filters designed to operate as depth filters would be replaced at or before the transition to surface filtration. For surface filters, the change from depth to surface filtration is very beneficial for filter efficiency; however, pressure drop across the filter increases with increased filter clogging and cake thickness, thus requiring more power to force air through the filter. Therefore, surface filters are typically regenerated by periodically blowing air through the filter opposite the flow direction to breakup and remove the filter cake.

Fibrous media are widely used in disposable filters, due to relatively low cost with acceptable performance. Most commercially available filters are either needled of felted to increase their strength and are usually supported by interlaced thicker fibres. They are composed of randomly oriented fibres, usually of varying length and thickness and can also withstand high temperatures and corrosive environments. They can be characterized as having low resistance to air flow, low pressure drop and, exceptional high filtration efficiencies (Bredin, 2012).

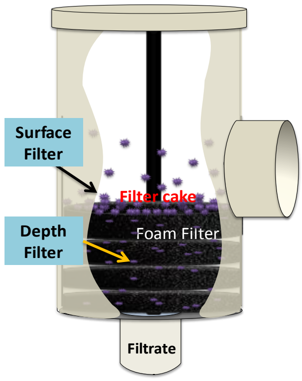


Figure 8: Fibrous filtration.

2.3 Water end use monitoring

The development of smart metering technology has eliminated the error associated with older end-use recording methods, resulting in more accurate records of end-use water consumption within residential households. Water end-use studies are becoming more common; however, the number of studies that quantify the actual savings a household could achieve through the reuse of GW is still low. Most recent residential end-use studies took place on the east coast of Australia (e.g. Beal and Stewart, 2011), and data cannot be accurately extrapolated to characterise Western Australians' outdoor lifestyle and water-consumption habits. Past research has shown that adopting effective water-monitoring techniques is an essential step in understanding domestic water-consumption habits (Stewart et al, 2010) and for establishing where improvements to assist in conserving water within the household can be made (Beal and Stewart, 2011).

The advent of smart water metering has enabled water consumption to be monitored at an end-use level, resulting in the identification of individual water-use events such as showering, toilet flushing, tap use, and irrigation, through the use of appropriate software (Willis et al., 2009; Willis et al., 2011).

However, determination of water consumption within a household is also dependent on numerous factors requiring specific knowledge on how, where, when, and who consumes water within it. Factors include the number of people in the house, age of residents, education levels of residents, lot size, residents' income, efficiency of water consuming devices (i.e. clothes washers, shower heads, tap fittings, dishwashers, and toilets), and the attitudes, beliefs and behaviours of consumers. Shifting residents toward sustainable water-consumption practices requires the instilling of awareness, understanding, and appreciation of the environment and water.

The uncertainty associated with traditional water meters to estimate the consumption patterns of GW captured has led to a search for more reliable ways to measure GW usage. Smart metering involves the application of a high-resolution water meter and a data logger to obtain a continuous record of water-consumption data and provide an accurate and timely view of water use to consumers (Anda et al, 2013b).

2.4 Australia's Water Future

The world's water scenario is changing rapidly. With factors including population growth, industrialisation, and urbanisation ever-increasing demands on freshwater resources (United Nations, 2015), a reduction in household water consumption is imperative. In this current global environment, GW recycling is a highly attractive option to meet the world's growing water needs.

However, in order to use our resources effectively, we must dramatically change the way water is used, managed, and shared.

The Water Resources Group expect the gap between supply and demand for safe freshwater will increase stating "the global water crisis is one of governance much more than of resource availability" (WWAP , 2015). The United Nations released its 2015 Revision of World Population Prospects, detailing the world's current and future population projections. Key findings revealed a current (2015) growth rate of 1.18% per year, predicting that the world's population will eventually reach 8.5 billion by 2030. If this growth is sustained, the world is set to face a 40% water deficit under the business-as-usual climate scenario (WWAP , 2015).

Over the last decade, Western Australia's population has experienced significant growth, with the current population of Western Australia standing at 2.57 million, a increase of 31.2% since the 2006 Census (ABS, 2008 to 2015). This unstable fluctuation in growth is not conducive to sustainable water management practices, and will place enormous pressure on meeting Australia's future water demands.

According to the latest edition (2013-14) of the Australian Bureau of Statistics (ABS) annual Water Account, Australia's total water consumption in 2013-14 was 18,644 GL. Of this, 16,772 GL (90%) was consumed by industry and 1,872 GL (10%) by households across Australia.

However, Western Australian household water consumption accounted for 26% (339 kL) of the state's total water use in 2013-14, one of only two states whose household water consumption exceeded that of agricultural water use. Household water consumption per capita in Perth was recorded as 132 kL per annum, well above the national average of 80 kL per annum.

All states and territories recorded positive population growth for the year ended 30 June 2015. Australia's total population as of June 2015 was recorded as 23.7 million, a 1.4% increase from the previous year. Victoria recorded the highest growth rate in 2015 of all states and territories at 1.7%, and Tasmania was the lowest at 0.4% (Figure 9).

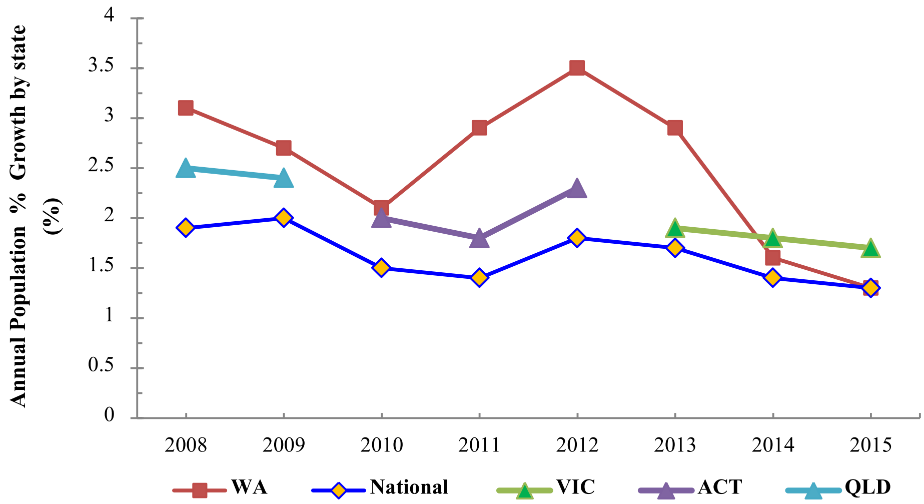


Figure 9: State population per centage growth.

The average Australian urban water price paid in 2013-14 by households was $3.08 per kL, with the highest state average reaching $4.29 per kL in South Australia. Western Australian households paid the second lowest for their water ($2.24 per kL) after the Northern Territory ($2.19 per kL). Prior to 2011, Tasmania was the highest water-consuming state in the nation (ABS, 2010-11).

However, records indicate that from 2011 to 2014 Tasmania has consistently had the largest per capita percentage decrease (54.4%) in household total water consumption while simultaneously experiencing one of the highest percentage increases (46.3%) in water pricing (ABS, 2012-13).

Western Australians on average pay considerably less than any other state for their water (Figure 10), though prices will inevitably be increased in an effort to reduce the state's household total water consumption. Over the last five years, the average per capita water consumption in Perth decreased by 9.7%, while the average household total water consumption only decreased by 8.3%, and in the last decade by only 10.9% (ABS, 2014).

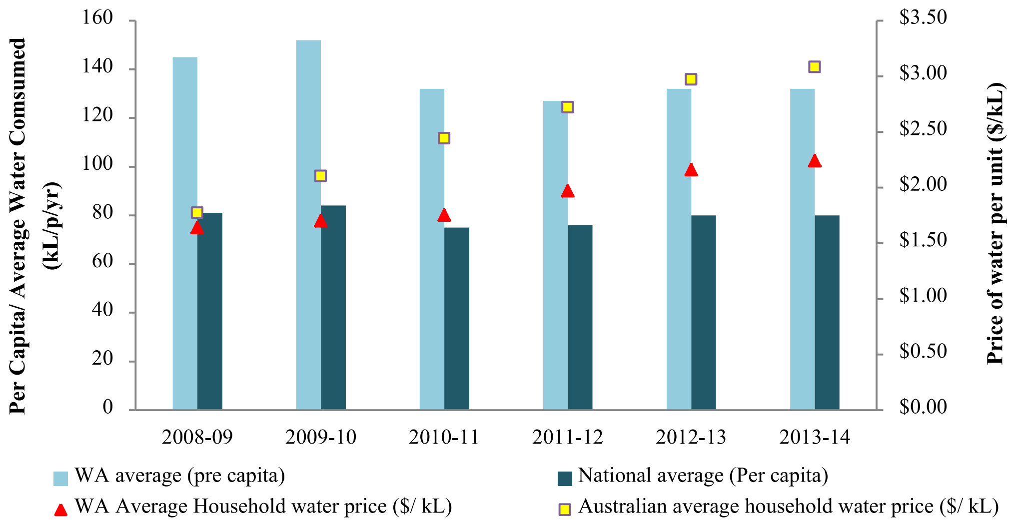


Figure 10: Comparing WA water usage and unit price to national usage, price since 2008.

As the world's population steadily grows, so too does global understanding of finite resources, with society increasingly looking towards technology to facilitate the epic task of managing natural resource usage.

Chapter 3

3 MATERIALS & METHODS

The focus of this chapter is to provide the reader with a visual description of the GWR test rigs experimental setup, including the experimental procedures used for the performance analysis of AWWS domestic GDD the GreyFlow PS Plug & Play.

The test rigs experimental setup combines three major subsystems (Figure 11) this enables the rig to be more versatile as a teaching tool; demonstrates the hydraulic principles of water recycling and greywater reuse systems; and in addition provides an accessible platform to conduct future research project.

Information presented within this chapter will describe each of the primary hardware components that have been used within the construction of the test rig and their basic functionality within each subsystem, exploring how each subsystem interfaces with each other and the test rig as a whole. Section 3.1 (Test Rig Design & Setup) describes the test rigs overall design by identifying the three main subsystems: flow control subsystem, greywater diversion subsystem, and data acquisition subsystem, providing a detailed outline of the systems overall mode of operation. Section 3.2 (Subsystem) presents each of the subsystems off-the-shelf components and devices. Analysing their basic functionality, mode of operation, and specifications.

Figure 11: Flow chart identifying the three main subsystems of the test rig used.

Note that all experiments were conducted using the GWR test rig located at the ETC, South East of Murdoch University, South Street Campus. Additional information within this chapter provides the reader with an understanding of the test procedures and techniques used for the experimental analysis of the GreyFlow PS Plug & Play GDD, the results of which are presented in Chapter 4 (Results & Discussion).

3.1 Test Rig Design & Setup

The test rig used for the performance analysis of the GreyFlow GDD is divided into three main subsystems. Figure 12 pictured below is a photograph of the actual test rig used for the performance analysis of the GreyFlow GDD, complete with the main components clearly labelled according to their respective subsystem.

The test rig shown in Figure 12 contains of the following main subsystems.

- Flow control subsystem, indicated by light blue labels. Comprised of the water inlet hose, two flow meters, one showerhead, one polycarbonate collection tank and one gate valve connected to a network of PVC pipes.
- Greywater diversion subsystems, shown in purple. Comprised of the commercially available GreyFlow GDD, the overflow reflux valve and the poly pipe drip irrigation kit including external pressure gauge.
- Data acquisition subsystem (DAQ), shown in green. Comprised of a HOBO U30 data-logger, one 25mm Elster water meter and two monitoring sensors; a split-cord AC current transformer, and a pulse input adapter cable with T-probe connection.

Note that in Figure 12, only the GreyFlow GDD and reflux valve are highlighted in purple (subsystem two), further examination of the GreyFlow GDD internal components functionality is presented in Section 3.2.2.

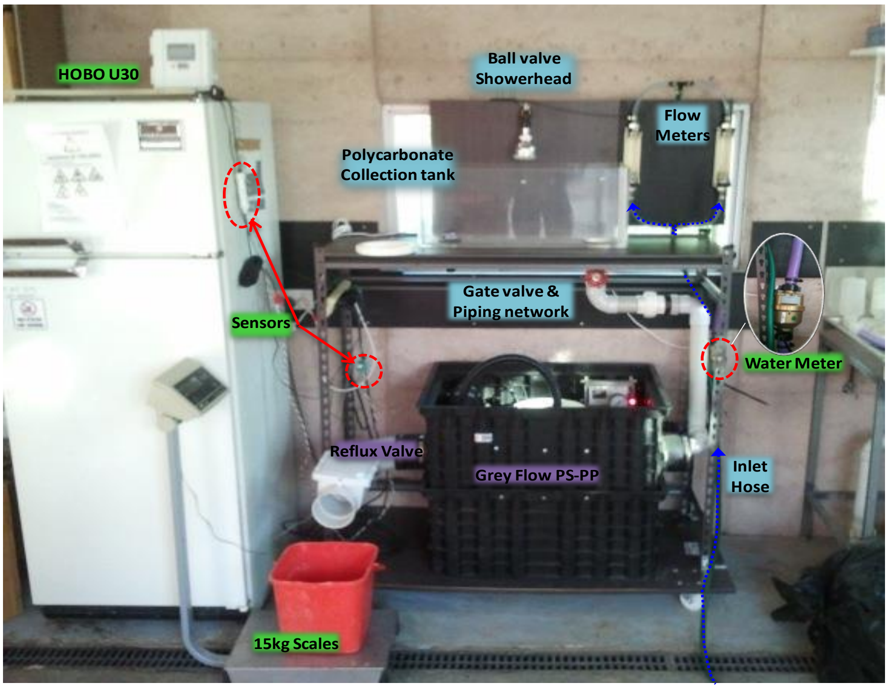


Figure 12: Picture of the GWR test rig at the ETC.

3.2 Subsystem

As the name suggests, the primary objective of a GDD is to divert GW from entering the sewer. This is achieved by directing the diverted GW through a set of polyurethane (PU) foam filters, before being discharged through the drip irrigation system out to the garden.

Figure 13 illustrates the test rigs flow relationship between the main components and each subsystem. By providing a visual representation with the blue arrows of fluid flow through the system. The support frame is constructed from a boltless storage unit shelving frame, fabricated by AWWS, Malaga, Australia.

The rig starts at the wall mounted inlet tap, from here water travels through the inlet hose and up through the parallel flow meters ($Flow_{max}$ 10 L/min each), were its discharged from the showerhead into the polycarbonate collection tank (tank capacity 31L). From there, water then travels down the drain through a gate valve and along a network (1.1 meters) of PVC pipes toward the greywater diversion subsystems' GreyFlow unit.

Water enters the GreyFlow unit (purple arrows) from the right, flowing directly into the first interceptor chamber (tank capacity 4.6L) where it's filtered through a stack of PU foam filters (15, 20, 25, 30 ppi) and collected in the surge tank (tank capacity 23.6L) until the signal is given by the float switch to begin pumping (this is explained in more detail in Section 3.3) out to the garden using the drip irrigation system.

The components used in the DAQ are primarily for the gathering of sensory data (sensor 1, 2), which is then relayed back to the HOBO data-logger monitoring system, where the data is then available to be downloaded onto a laptop, using HOBOware software (Figure 13).

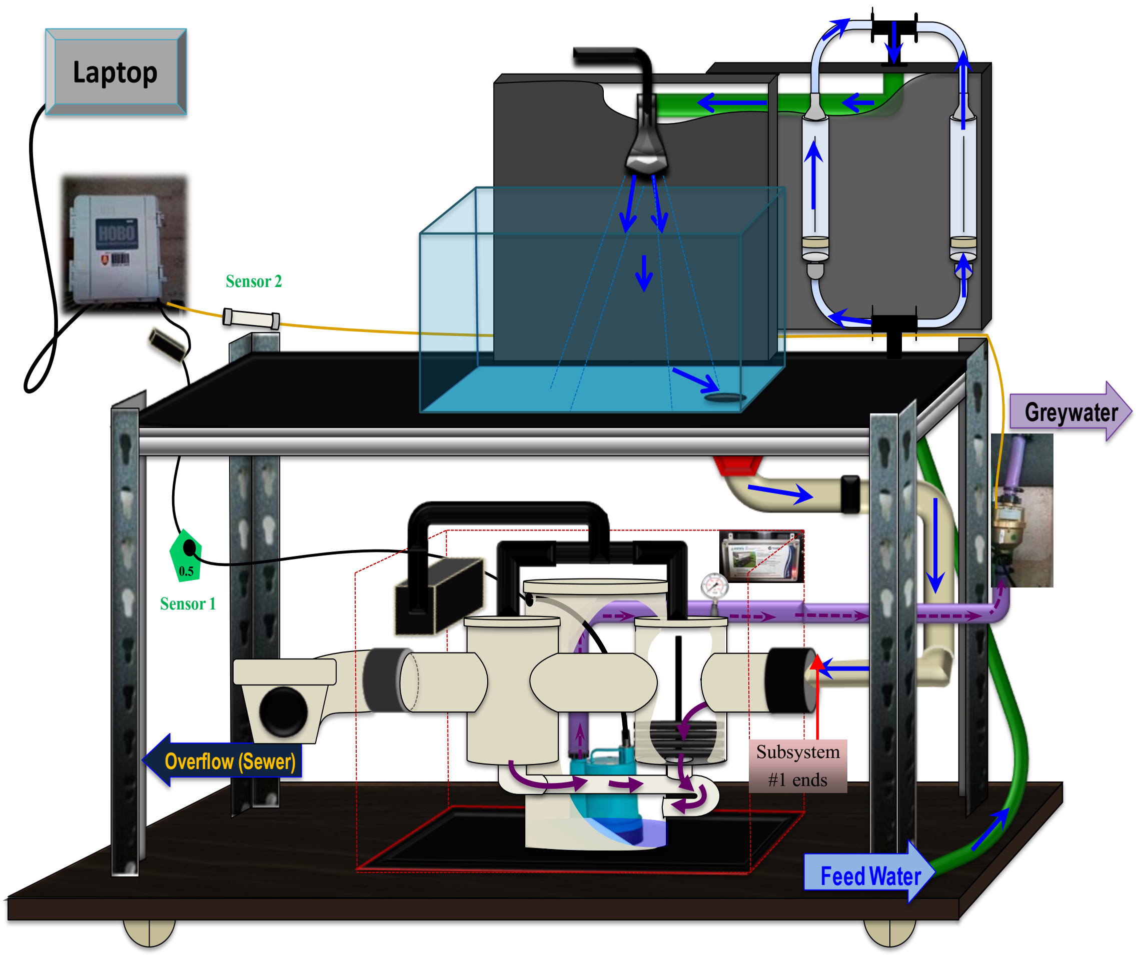
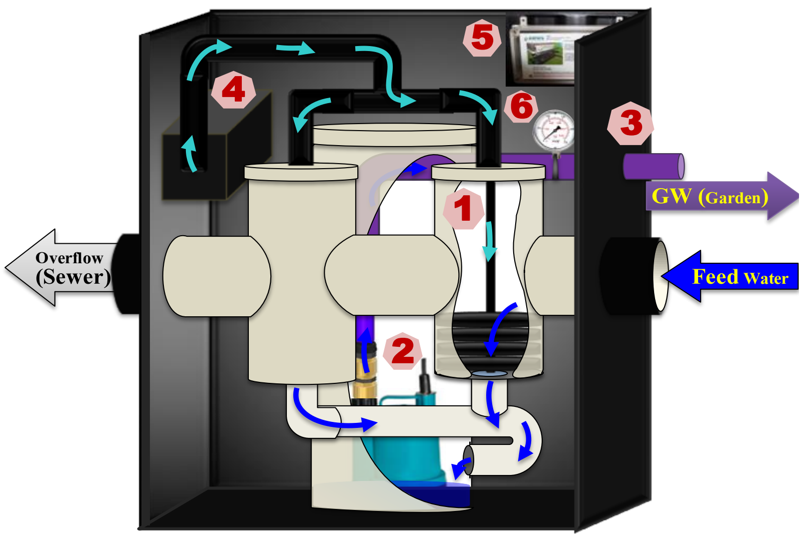


Figure 13: Flow diagram of the GWR test rig at the ETC.



Core Components:

1. Interceptor Chambers with Filters
2. Surge Tank & 100 Watt Pump
3. Pump Outlet Pipe
4. 200 Watt Air-blower
5. Automated Controller Box
6. Pressure Gauge

Figure 14: Illustration of AWWS Domestic GreyFlowPS-Plug & Play (Short) GDD.

3.2.1 Flow Control

The flow control subsystem contains the following:

- Two flow meters
- One showerhead
- Two control valves (ball, gate)
- One polycarbonate collection tank
- One garden hose with adapters
- Length of Clear tubing, hose clamps and fittings
- PVC (DWV) pipe and fittings

These key pieces of flow control equipment make up the test rig. The process starts with the two identical Platon flow meters arranged in parallel (Figure 15) each capable of delivering up to 10 litres per minute to produce a combined flow of 20L/min; however, due to ETC plumbing (bore connection), the maximum combined flowrate was reduced to 17 litres per minute. Connected to the flow meters (1m of hose) is a ball valve operated showerhead that is centred above a polycarbonate collection tank (Figure 15). The underside of the collection tank has a gate valve connecting the AWWS GreyFlow diversion unit via a network of pipes (Figure 16). This design enables the user to regulate the flow of water manually by opening or closing the water inlet tap or the gate valve connected to the drain.

Flow meters: Two Platon variable area flow meters (10L/min), capable of delivering a combined maximum flow of 17 litres per minute.

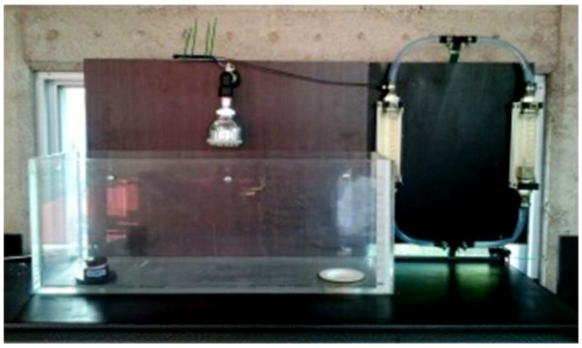


Figure 15: Parallel flow meters and collection tank.

Flow measurement is the quantification of bulk fluid movement. Flow can be measured in a variety of ways. Positive-displacement flow meters accumulate a fixed volume of fluid and then count the number of times the volume is filled to measure flow. Other flow measurement methods rely on forces produced by the flowing stream as it overcomes a known constriction, to indirectly calculate flow. Flow may be measured by measuring the velocity of fluid over a known area.

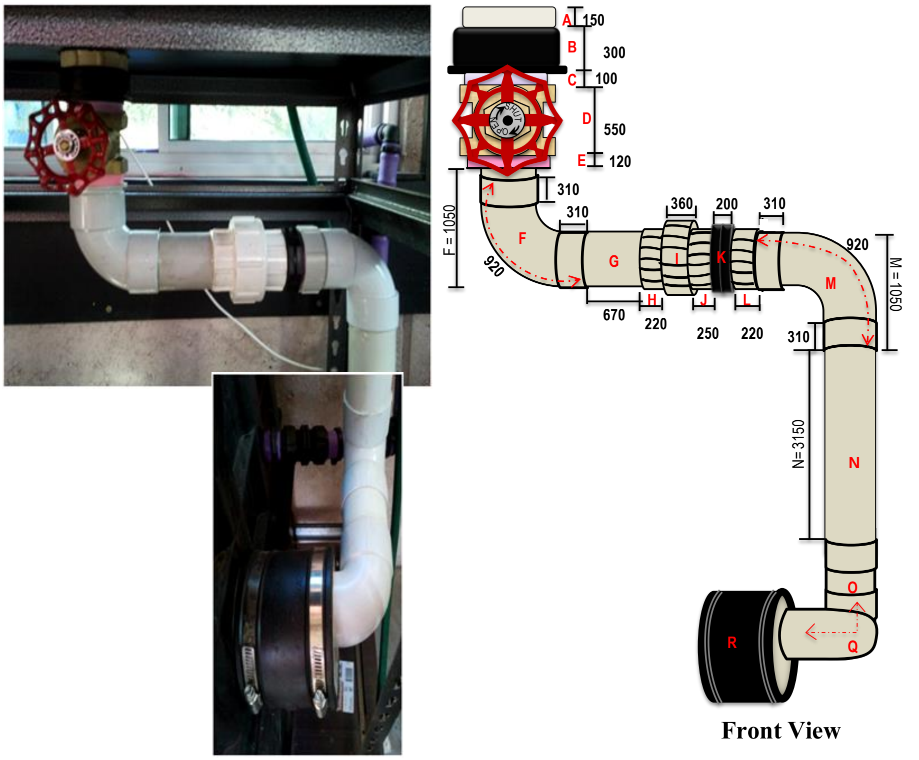


Figure 16: Network of PVC pipes with gate valve control.

Table 1: Platon flow meter.

Model: PGB4 - EAU (*Variable area flowmeter*)		**Platon**	
Max flowrate (L/min)	10 $_{(ea)}$ or 20 $_{(combined)}$	Tube	TPX plastic
Flow Range	1-10 L/min	Float	Stainless Steel
Op. Temp$_{(Water)}$	80 ^{o}C	Connections	½’’ Brass
Op. Pressure	10 Bar G	Nominal Diameter	2.5 cm (1”)
Accuracy	±5% FSD	Dimensions	250 x 67 x 67
Installation	Install vertically with flow upwards, reading float top edge		

3.2.2 Greywater Diversion Subsystem

The GW Diversion Subsystem consists of the following:

- One GreyFlow PS plug & play GDD
- One outdoor pressure gauge
- One GreyFlow Drip tube irrigation kit
- One reflux valve
- 100m of 25mm purple LDPE poly pipe
- PVC pipe and fittings

The 'GW Diversion Subsystem' primarily consists of AWWS commercially available domestic GreyFlow PS Plug & Play GDD. In addition to the GreyFlow unit, the subsystem also contains a reflux valve connected to the overflow pipe, one outdoor pressure gauge and 100m of poly pipe drip irrigation kit.

The fully automated system is controlled via a wall mounted controller box seen in Figure 14 (#5) with air assisted self-cleaning back-flush (#4) scheduled on a ten cycle rotation. AWWS GreyFlow GDD is designed to only filter incoming GW, diverting the filtered water to the garden via a drip irrigation network. Figure 14 shows a flow diagram illustrating the flow paths of feed water and air within the GreyFlow systems. Continuing on from the previous subsystem, water flows through a series of PVC pipes connecting the collection tank above to the GW unit below. Water enters the GreyFlow system through a side inlet pipe, flowing directly into the primary interceptor chamber, where it then passes through a series of polyurethane (PU) foam filters (#1), draining into the surge tank (#2).

This process is repeated for any water that flows over into the second interceptor chamber during normal operations as a result of high input volume or flow velocity. Water is collected and stored briefly in the surge tank before being pumped outside through the drip irrigation network of pipes (#3). However, water that flows over into the second interceptor chamber during air assisted back-flushing is discharged to the sewer along with any lose debris lifted from the filters.

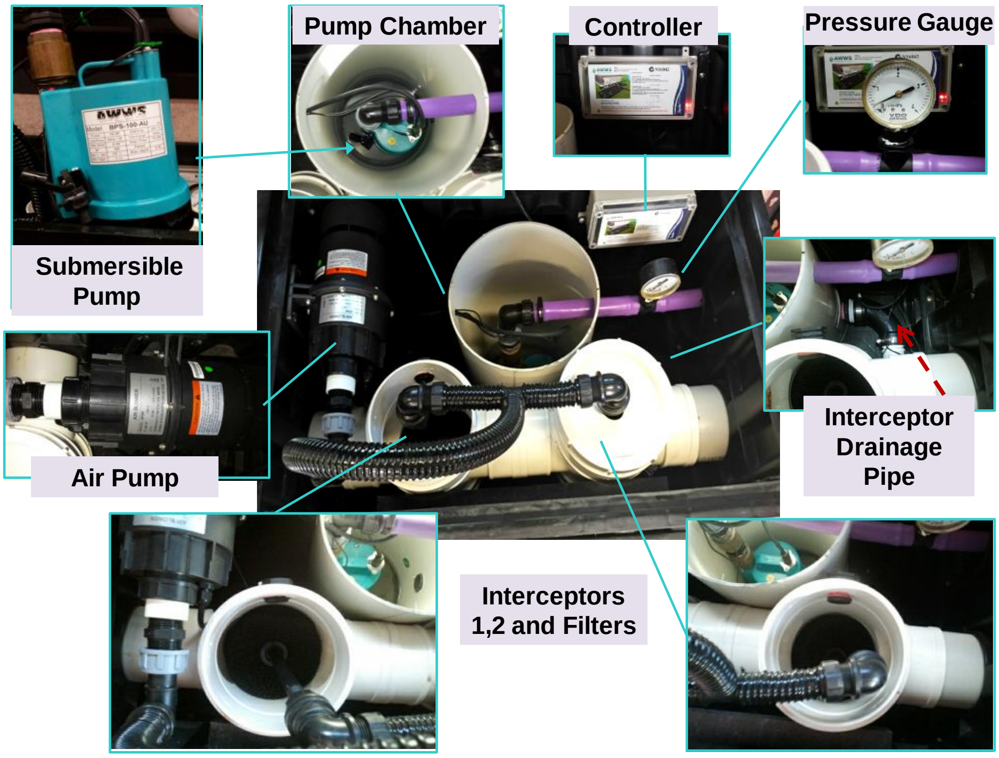


Figure 17: A labeled 'Top view' Photograph of the rigs GDD.

Foam Filter: This is specifically called the 'Open Cell Reticulated Polyurethane Foam', as both interceptor chambers have gradient-layered foam filter with the larger pore sizes on top and smaller pore sizes located at the bottom, with each layer approximately 2cm thick. Figure 18 shows that the stacked gradient is a method of combining layers of different low-density rigid foam layers, in top down increased porosity, with 15 Ppi, 20 Ppi, 25 Ppi, and 30 Ppi. Ppi represents the porosity of the foam and stands for 'pores per inch'.

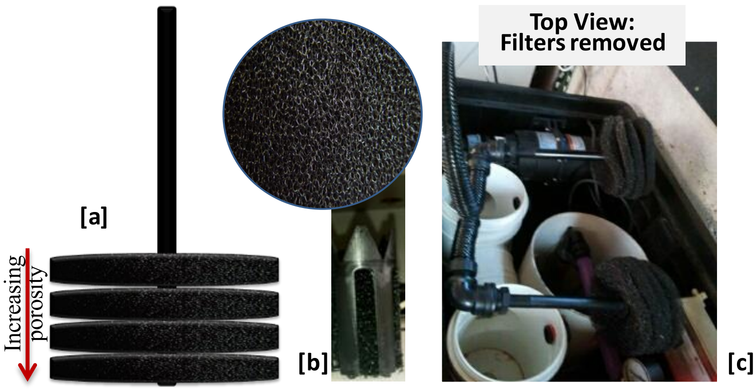


Figure 18: PU foam filters used in the GDD.
[a] Stacked interceptor chambers foam filter, [b] Interceptor chamber drainage pipe final filter, [c] Top view of GDD with both stacked filter columns removed from interceptor chambers.

Pump Chamber and Pump: The BPS series pump used within the GDD is a 100 watt centrifugal submersible pump that requires a 240-volt power supply (Table 2). The submersible in-tank or 'sump' pump is specifically designed to be used in narrow tanks, constructed in thermoplastic and stainless steel. The pump is capable of delivering 70 litres per minute through a vertical discharge shaft as illustrated in Figure 19. The pump is controlled via a horizontally mounted float switch connected directly to the wall-mounted controller, this dictating how the pump operates using an on-off flow control method, due to the varied incoming flow.

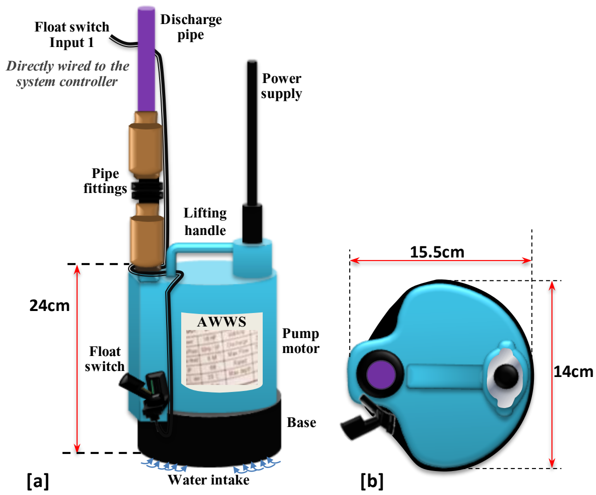


Figure 19: The GDD 100 watt submersible sump pump.

Table 2: Pump specifications (AWWS)

Model: BPS-100-A(V)		**AWWS**	
Power output	100W (1/6 HP)	Volt/Amp	240V /1A
Cycle/phase	50Hz /1P	Discharge outlet	25mm
Max. Head	6m	Max. Flow	70L/min
IP	68	Rated: Head, Flow	6m , 8L/min

LX Air-Blower: The AP series air blower used within the GDD is a 200 watt double impeller centrifugal air blower that requires a 240-volt power supply (Table 3). The pump operates at a low 65dB, capable of delivering 1.3 cubic meters of air per minute at a pressure of 0.9 psi. The casing is reinforced and designed to withstand high temperatures. The air blower's average energy consumption during backwashing is 0.07kWh.

Figure 20: 200 watt air blower pump, used to assist backwashing.

Table 3: Air pump(blower) specifications (LX pump)

Model: AP200 – Centrifugal Air blower **LX**		**V2 – "**Double" Two stage impeller	
Rated Power	200W	Noise (dB)	65
Max. Flow	1-1.3 m^3/min	Cycle /phase	50 Hz [0.25 HP]
Max. Pressure	0.87 psi or [0.006 MPa]	Weight	2.6kg
Rated Voltage	240V	Insulation	Type F
Current (A)	1.2 A	Size (mm) LxW	[262 x 138]

Time Delay and Pump Controller: Pictured in Figure 22

The pumping time delay was performed by a NE555 monostable monolithic integrated circuit (IC) The single 8 pin timer is a highly stable, used for generating accurate time delays. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. The timer is programmed to automatically turn on once the float switch is trigged the pump after a pre-determined delay has elapsed as by the, and turn off when the float switch on the tank water level. Figure 22

Figure 21: GreyFlow PS PnP wall mounted controller.

The test rig performed baseline dataset trials using two different NE555 IC timer; performances were monitored looking for any performance variations in cycle time durations, energy use, and overall efficiency.

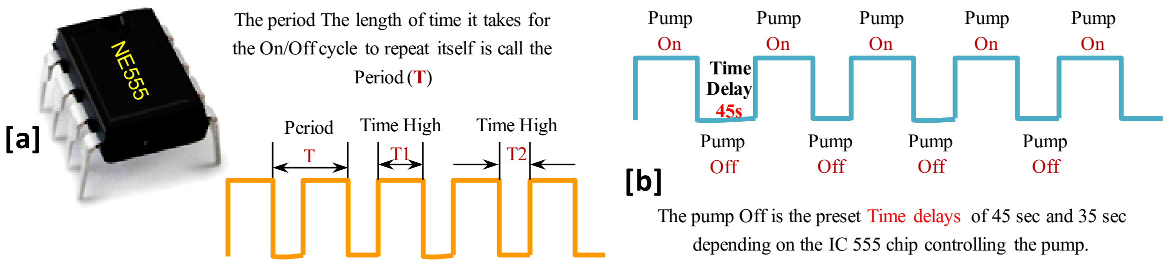


Figure 22: NE555 integrated circuit used as a timer[a] and pumping duty cycle[b].

The start and stop levels for operation of the pump are specified at the design stage. When the level of the greywater exceeds the start level (Level 2), the time delay is activated once completed the pump will automatically starts to operate. Correspondingly, when the level of the greywater drops to the stop level (Level 1) the pump stops. This makes the pumps operate according to the different levels of greywater. Controlling the wastewater levels in the collection tank of the GDD is based on the sensors providing information about the wastewater level. Typical methods for controlling the wastewater level are float switches, pressure transmitters and ultrasonic devices.

3.2.3 Data Acquisition Subsystem

The data acquisition subsystem consisted of the following:

- One Onset HOBO U30 Wi-Fi: remote monitoring system
- One HOBOware software package
- One Elster V100(PSM) water meter
- One data logger with T-probe cable
- One 0.5 AC current transformer
- One laptop with 5 pin mini USB cable
- One electronic weighing platform scales (15kg max)

The objective of using a data acquisition device was to measure the energy use of the pump and air blower and the water meters discharge volume obtained from the data logger. Results of the energy used compared with flow characteristics will be discussed in the Chapter 4 (Results & Discussion).

The current transformers role within this project is to measure the total current consumed by the system to determine the total energy consumption. The data is then used to calculate the power being consumed by the system. Sensors such as 'plug-n-play adapters' are installed in the system to carry out monitoring and data acquisition.

The AC energy sensor is made of the following components: a current transformer (CT) transducer and pulse input adapter cable.

Mini Split-core CT: The Mini AC Split-core current transformer (CT), shown in Figure 23, is clamped around the active line supplying all the GDD with power. Designed to measure the AC amperage being produced when connected to the current carrying wire. Following is a two-channel Flex Smart True RMS (Current/ Voltage Module). This component is designed to work with the smart sensor plug-in of the HOBO data logger. The HOBO U30 automatically saves the data from each experiment, where it remains until the user downloads the data and converts the [.csv] file format to an Excel spreadsheet format [.xls] for further analysis of the results. The process for obtaining sensory information is discussed in a later section.

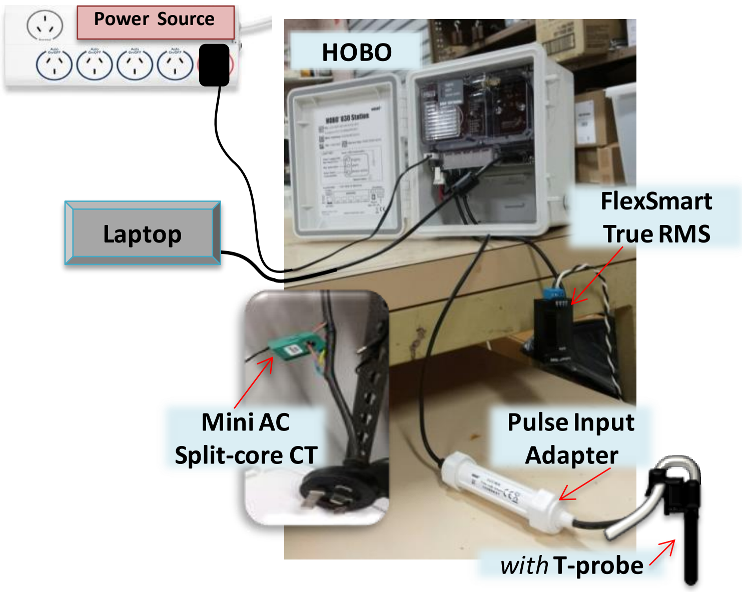


Figure 23: HOBO Data logger with monitoring sensors.

Table 4: Split-core AC Current Transformer specifications.

0.5 AC Mini Split-core (CT)		**HOBO**	
Rated input:	1 to 75 AMPS	Volt/Amps $_{\text{Output}}$	0.333 Volt AC
Operates:	50- 400 Hz	8 ft. twisted	-pair lead
CT size	5 A	Specific Power factor	0.95
Accuracy:	10% to 130% of rated current & ± 1% (Linearity accuracy)		

Table 5: Pulse input adapter cable specifications (HOBO)

FlexSmart True RMS- [S-FS-TRMSA-D]		**Onset**	
Input Channels:	2	Field wiring: 2	screw terminals
Maximum input:	±1V	Dimensions:	(3.5x 5.7x 1.9)cm
Minimum input:	5mV	Cable Length:	17.8 cm
Resolution:	12-bit	Weight:	21.2.g
Accuracy:	±0.3% of reading ±0.5% FSR*		
Range:	5mV to 512mV input compatible->333mV FS Output sen		

Water Meter: The Volumetric Rotary Piston Water Meter, illustrated in Figure 24, is the 25mm Elster V100(PSM-T), Class 2 positive displacement meter, designed to measure potable water either manually or electronically using a data logger for real-time pulse recordings where each magnetic pulse is equivalent to 5L volume (1 pulse/5L) of recorded consumption. A pulse output lead can be connected between the water meter and a data logger to allow logging of water usage according to the number of pulses received. The number of pulses is aggregated by the data logger according to programmable timed intervals (seconds in this case), so that a water usage profile is built according to the number of pulses received per interval.

The V100 meter uses a rotary piston to mechanically rotate the water counter, which in turn displaces a set volume of water through the meter. The water meter is positioned outside of the GDD box, connected to the pump discharge pipe, where it physically records the volumetric amount of water that is discharged outside via the drip irrigation system.

Figure 24: Illustration of the Elster V100 PD water meter.

Table 6: Water meter specifications (Elster)

Model: PD V-100(PSM-T)		**Elster**	
Min flowrate Q_1 $\pm_{5\%}$	20 kL/h	Accuracy Class	2
Trans flowrate Q_1 $\pm_{2\%}$	32 kL/h	Pulse output volume	5 L/pulse
Max flowrate Q_3 $\pm_{2\%}$	4.0 kL/h	Op. Temp$_{(Water)}$	50 ^{o}C
Flowrate ratio Q_3/Q_1	200	Max. Temp$_{(Working)}$	30 ^{o}C
Overload flowrate Q_4 $\pm_{2\%}$	5	Max. Pressure	1600 kPa
Installation	Vertical/Horizontal	Nominal Diameter	ND25 (mm)

3.3 Data Collection

This section is designed to provide a clear understanding of the physical processes used to collect flowrate baseline data, as well as present a detailed explanation of any terminology relevant to this report.

to investigate the effects of clogging, on filter permeability and pump energy demands.

This section provides the data collection details of the filter clogging experiments.

This section explains the systematic approach that was used to collect and analyse the raw data. In order to address the specific objectives outlined in Chapter 1 (Introduction), a relationship needed to be established between the pumps discharged flowrate and energy consumption. Note that all the baseline performance characteristic results are graphically presented and detailed in Chapter 4 (Results & Discussion), with particular attention to the total quantifiable water and energy savings.

The experimental analysis and data collection approach used to evaluate and compare both time-delay chips and establishing baseline flowrate data for comparison is explained in detail in section 3.3.1- Baseline trials.

Baseline trials were conducted in order to establish a standard by which both IC time-delay control chips can be measured against, thus enabling a repeatable comparison of Chip A-(45s delay) and Chip B- (35s delay) cycle sets. By pairing the data from both IC control chips by flowrate, a complete performance breakdown was performed on each flowrate baseline trail.

Flow characteristics identified during baseline trials, includes the following:

Pumping cycle time	Backwash cycle time	Overflow Volume lost to sewer
Pump Energy demand	Time Duration /Cycle Set	Overflow discharge flowrate
Total number of Pulses	Pump Energy use	Time Delay between cycles
Pump discharge flowrate	Air-blower Energy use	

Terminology:

A "Baseline" is a reference point or a standard by which things can be measured and compared against. A "Cycle" is an interval of time during which a repeated action is completed.

A "Cycle Set" is the period of time taken up by the recurring succession of events (events repeated again and again in the same order), generally performed by a machine and always returning back to the starting point before repeating the sequence of events.

A "Baseline Trial Run" is the term given to describe the data collection method used to establish performance characteristics over a range of flowrates. One baseline trial run contained the same sequence and number of events: 10 alternating pump cycles (On/Off) concluding with 1 back flushing cycle (air blower), completing the cycle set and returning to the start to repeat the sequence again. The repeated sequence of pump cycle events that occur between each back flushing cycle (Air blower), together with the total number of pulses events that occurred during each individual flowrate baseline trial represent one complete cycle set.

. Figure 25 provides a schematic of the flow terminology.

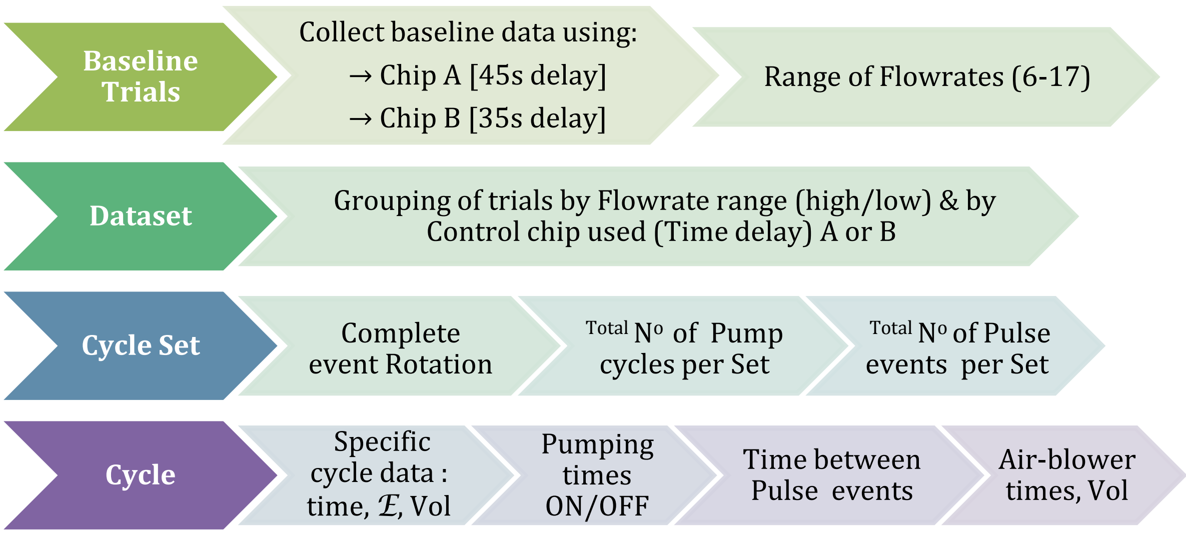


Figure 25: Terminology – breakdown of what makes up each system.

3.3.1 Baseline Trials

Accurate baseline data was obtained using three control chips to monitor and record the systems overall running performance and to compare the previous (original) chips cycle configuration programme with the newly implemented controller chips Figure 26.

Different IC controller chips were as follows:

1) Demo chip: Time delay 45 second, 3 pump cycle air-blower activation.
2) Chip A: *(Original)* Time delay 45 seconds, 9 pump cycle air-blower activation.
3) Chip B: *(New)* Time delay 35 seconds, 10 pump cycle air-blower activation.

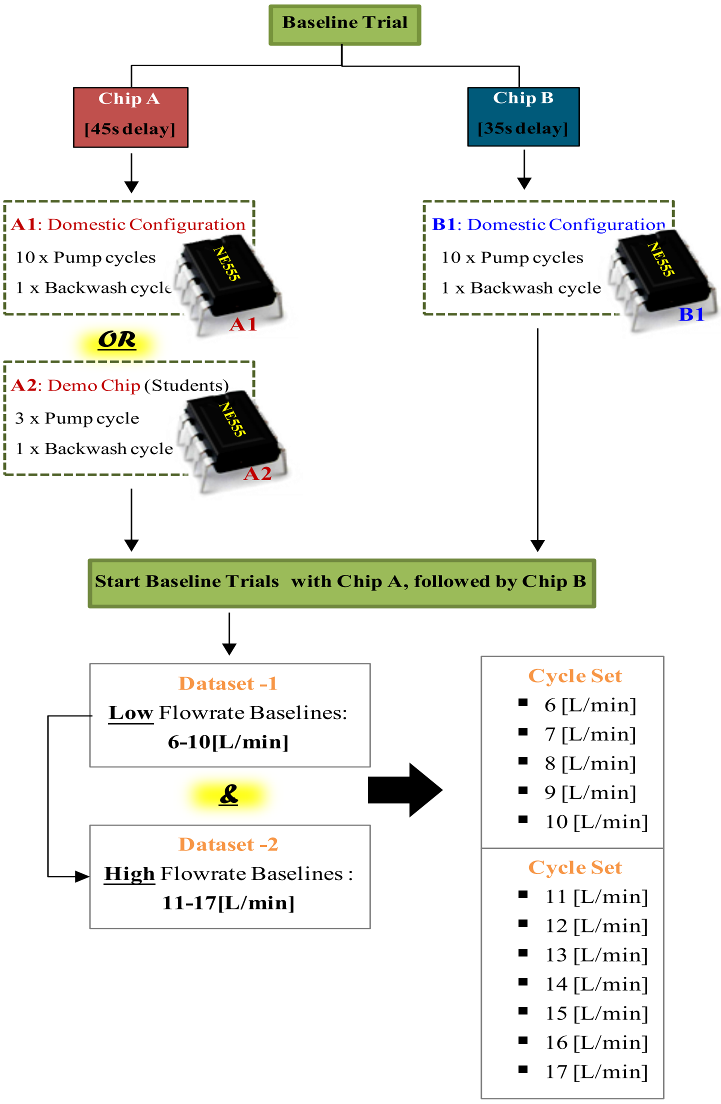


Figure 26: Process for determining flowrate baselines.

Baseline Trial Procedure:

The experimental test rig was setup to produce a flowrate baseline dataset (Figure 12). The data sets consist of 12 run-to-completion cycle sets obtained from well-controlled GW diversion experiments. Each baseline cycle set is unique to a specific flowrate, and the task of sifting through tens of thousands of lines of raw data is a laborious, requiring many hours of sitting in front of the computer looking for a flow pattern. The data relates to power consumption and water discharged over time. Data was obtained by monitoring these variables over the duration of each flowrates cycle set. The improvements in the system design (float switch) and data collection mechanism resulted in the collection of reproducible and well- organised data sets. A brief outline of the data collection mechanism is provided next.

A flowrates baseline is defined by its cycle set data. To determine each flowrates 'normal' operating baseline parameters, the following tests and measurements were used to analyse and understand specific flow and cycle patterns associated with the rig.

Each flowrate was tested, producing a baseline to compare it against. Each baseline is one complete cycle for a given flowrate, which consists of 10 pump cycles, followed by a 2-minute, 30-second air blower cycle. Identical sets of baseline trials were performed using both IC delay chip over a set range (6 to 17 litres per minute) flowrates. This was done to establish each delay chips specific baseline performance characteristics over an identical range of flowrates

Before baseline trials started, it was necessary to connect the HOBO U30 station using a mini-USB cable to a computer running HOBOware software. The status bar at the bottom of the HOBOware window verified connection status in order to run the HOBOware software. This section describes the procedure for connecting the HOBO U30 Station to a computer running HOBOware software.

To illustrate the operating procedure for determining the baselines of the system, the following series of steps were performed: Baseline trials for the 45s delay chip used the demo IC chip; the demo chip has a complete cycle set of only 3 pump cycles followed by the air blower cycle. This was used for both the low-flow and high-flow values; the reason for the change in chip was in an attempt to reduce the total volume of water being lost to the sewer. The 35s delay chip was used to run all baseline trial runs – the chip has a standard operating 10 cycles per complete set.

Baseline Trials (45s Chip)

Experimental trial runs (set) were conducted for flowrates 5 to 17 (L/min) to establish the various baseline characteristics of each flowrate.

Operating Procedure

Step 1
- Open the feed inlet water tap to the desired flowrate, by visually monitoring the parallel flow meters indicator gauge (combined readings to equal the actual flowrate).

Step 2
- Launch the HOBOware program to start recording. Stop only at the end of the data set of baseline flowrate trials (i.e. 6-10 L/min). Details are provided below in the section titled 'Launching HOBOware Software (Data Retrieval)'.

Step 3
- During the air blower cycle, overflow water is collected and weighed using the Electronic Weighing Platform Scales (max weight is 15kg).

Step 4
- Once the air blower cycle has finished and the pump has initialized, this signals the end of one flowrate trial run and the flowrate rate can be increased.

Step 5
- The HOBO system will keep recording during the change in flowrate. The first pump cycling of each trial run is dismissed as the changeover period.

Step 6
- Repeat the above process always in ascending flowrate order.

Step 7
- Stop HOBO device when all trial runs 5 to 17 (L/min) are complete.

Launching HOBOware Software (Data Retrieval and Analysis)

- Open the HOBOware Software by clicking the desktop icon.
- To start program recording, click the 'Launch Device' icon.
- Stop program recording by clicking 'Stop Device' icon.
- To retrieve the recorded data, click the 'Readout Device' icon.
- Save the [.dtf] file and select plot graph.
- Click 'Export Table Data' icon ; select 'Export to single file'.
  - ➔ Save the Excel worksheet as [.csv] file first,

Then select 'Save As' the [.xls] file to enable changes to be made..

3.3.2 Filter Clogging

Opting for a laboratory-based approach to investigate the effects of clogging, on filter permeability and pump energy demands. However, due to time constraints as a result of injury the original approach chosen to test the affects of clogging was no longer practical within the time remaining. The following section will present the original experimental design followed by the actual experimental method used instead.

The flowrate chosen to model clogging affects on was 9 L/min, as it's conceded the average domestic flowrate. Trials using spherical disk cut to the same size as the foam filters to simulate clogging. The disks were fabricated from various types of textile wadding, a synthetic (polyester), a Bamboo/Poly blend and a natural (wool). Each disk are to be lightly coated repeatedly with a bonding/adhesive (light not superglue) spray, slowly building up the layers by randomly block pores with each application, similar to filter cake build up in the real world. To ensure each disk reaches its desired percentage clogged, the disk must be tested regularly to establish the level of clogging achieved.

This is achieved by placing inside a Büchner funnel the disk being tested on top of one of the current filters (create air gap between the funnel and the disk being tested) and time how long it takes for water to permeate through, establishing what percent it's clogged by.
However, due to reasons already stated, the simulated clogged experiment was not conducted that way, instead multiple layers of textile wadding disks were used to simulate clogging as shown in Figure 27. By creating a larger more dense surface area for the water to travel through, with the aim of reducing the waters velocity and potentially affect the cycle time duration of the pump.

Examining the results of the first trial using one clogging disks showed no change in the flowrate time cycle duration.

H2 Flowrate Backwash Overflow Volume

present zero change for all filter clogging trial runs.

This trend continues when the number of clogging disks is increased to two; again, the disks were sandwiched between the actual foam filter layers with results inspected during mid-cycle via the HOBOware software.

Results again revealed zero change in any of the flowrates time cycles. The final clogging test was performed with the addition of four clogging layers, no noticeable variation (Figure 28) when compared to with the original baseline values of 9 L/min.

Data once again showed that there was no noticeable change in the time required to filter water through the clogging disks. An additional complication came from stacking multiple layers of disks, which had started to interfere with the direct flow of the incoming water, thus preventing any further testing to take place. As a result, the stacked filters created an added height that directly impacted the flow and ability to divert to the next chamber, which in turn affected the parameters of the permeability tests.

Figure 27: Filter clogging experimental design an setup.

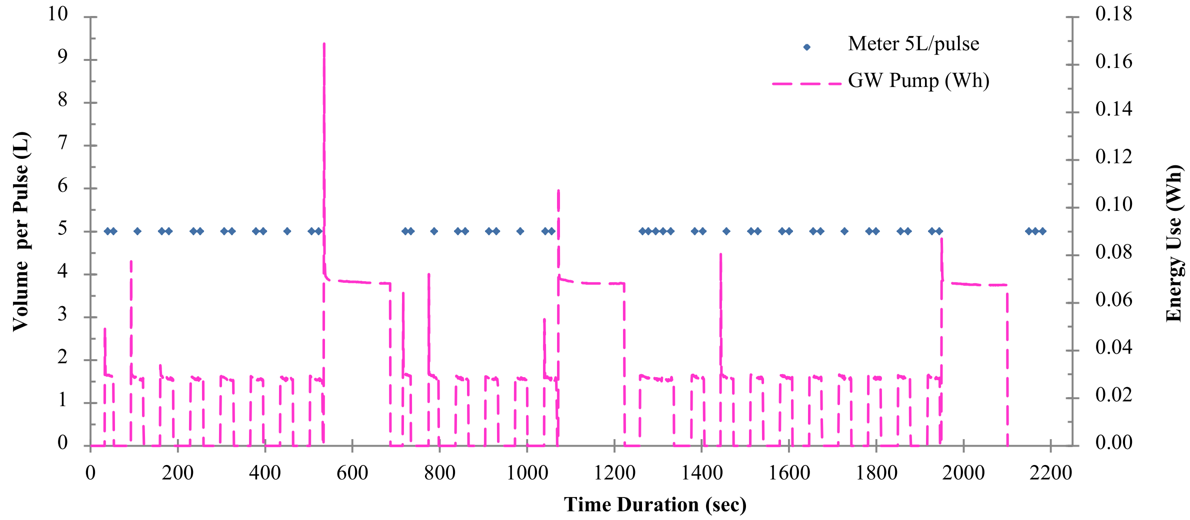


Figure 28: Pump energy during filter clogging experiments.

3.4 Data Analysis – Calculations

Area of a pipe:

$$A(\mathrm{m}^2) = \frac{\pi D^2}{4}$$

Average Velocity through a pipe:

$$\bar{u}\left(\frac{\mathrm{m}}{\mathrm{s}}\right) = \frac{\dot{m}}{\rho A}$$

Mass, Velocity & Volumetric flowrates

$$\dot{m}\left(\frac{\mathrm{kg}}{\mathrm{s}}\right) = \rho\dot{V} \;\rightarrow\; \rho(\dot{u}A) = constant \qquad \dot{V}\left(\frac{\mathrm{m}^3}{\mathrm{s}}\right) = \dot{u}A$$

$$\dot{V} = (A_1\dot{u}_1 = A_2\dot{u}_2\,) \;\rightarrow \left[\pi\frac{D_1^2}{4}\dot{u}_{\,1}\right] = \left[\pi\frac{D_2^2}{4}\dot{u}_{\,2}\right] \qquad \rightarrow\rightarrow\; \dot{u}_{\,2}\left(\frac{\mathrm{m}}{\mathrm{s}}\right) = \left[\frac{D_1}{D_2}\right]^2 \dot{u}_{\,1}$$

3.4.1 Flow Characteristics

Reynolds number:

$$N_{Re} = \frac{\rho \bar{u} D}{\mu}$$

Friction Loss:

$$E_{f,major}\left(\frac{\mathrm{m}^2}{\mathrm{s}^2}\right) = 2f\left[\frac{\bar{u}^2\, L_T}{D}\right]$$

Friction losses due to the pipe roughness and fitting

Friction loss for standard fittings:

$$Fittings_{\substack{friction \\ loss}} = \left(\frac{L_e}{D}\right)$$

Equivalent length:

$$L_e = D_{ID} \times \sum\left(\frac{L_e}{D}\right)$$

Total length:

$$L_T = \left(L_{\substack{straight \\ pipe}} + L_e\right)$$

3.4.2 Quantification of Water Captured

Data from the data logger needed to be extracted from the HOBO [.csv] files; the unit pulse data was used to quantify the total volume that the pump discharged during the one complete baseline trial run. An extract of this information from the column D was done by selecting the "Data Filter" tab and the number one (1) as the only values wanting to be displayed. For every one (1) pulse recorded, a five (5) litres volume of water was discharged by the pump over a set time interval – the time duration was the number of seconds the pump was active between each recorded pulse (called the 'pulse cycle' (Figure 29).

The following equation was used to determine the pumps discharge volumetric flowrate:

$$\dot{V}_{Dis}(L/s = \frac{P_v\ (5\ litres\ /\ Pulse)}{P_c(Sec\ /\ Pulse)}$$

Where: P_v = Pulse volume (L)→ *Set volume (5 litres) per pulse*

P_c = Pulse cycle (s)→*Number of seconds the pump is on between pulses*

$\dot{V}_{Dis}$= Pump Discharge flowrate (L/s)

The data was converted into litres per min and used to quantify the total water volume of water captured by the GDD. A comparative analysis of the pulse cycle time internals for each flowrate was conducted to determine if a specific time interval was recorded the most. This labour intensive exercise of counting of each set of pulse cycles was sped up by using the formula =IF (I18>1, 1,) which reduced the length of time spent counting each cell. The results demonstrated that although there was a wide range of time intervals, the majority of pulse cycles showed 17 seconds to be the most common time interval across all flowrates.

One pulse cycle (5L/s);

5L per **18** sec = 0.28L/s **or** 278mL/s **or** 16.7L/min.

5L per **17** sec = 0.29L/s **or** 294mL/s **or** 17.6L/min.-[The most appropriate fit]

5L per **16** sec = 0.31L/s **or** 313mL/s **or** 18.8L/min.

5L per **15** sec = 0.33L/s **or** 333mL/s **or** 20.0L/min.

5L per **12** sec = 0.42L/s **or** 417mL/s **or** 25.0L/min.

402	8/06/2015 12:24:40 AM	1	29.298	Time(s)
403	8/06/2015 12:24:41 AM	0	29.376	1
404	8/06/2015 12:24:42 AM	0	28.86	2
405	8/06/2015 12:24:43 AM	0	29.157	3
406	8/06/2015 12:24:44 AM	0	28.938	4
407	8/06/2015 12:24:45 AM	0	29.688	5
408	8/06/2015 12:24:46 AM	0	29.282	6
409	8/06/2015 12:24:47 AM	0	29.188	7
410	8/06/2015 12:24:48 AM	0	29.188	8
411	8/06/2015 12:24:49 AM	0	29.204	9
412	8/06/2015 12:24:50 AM	0	28.563	10
413	8/06/2015 12:24:51 AM	0	29.22	11
414	8/06/2015 12:24:52 AM	0	28.813	12
415	8/06/2015 12:24:53 AM	0	21.891	13
416	8/06/2015 12:24:54 AM	0	0	
417	8/06/2015 12:24:55 AM	0	0	
418	8/06/2015 12:24:56 AM	0	0	
419	8/06/2015 12:24:57 AM	0	0	
420	8/06/2015 12:24:58 AM	0	0	
421	8/06/2015 12:24:59 AM	0	0	
450	8/06/2015 12:25:28 AM	0	0	
451	8/06/2015 12:25:29 AM	0	0	
452	8/06/2015 12:25:30 AM	0	0	
453	8/06/2015 12:25:31 AM	0	30.642	14
454	8/06/2015 12:25:32 AM	0	30.704	15
455	8/06/2015 12:25:33 AM	0	30.642	16
456	8/06/2015 12:25:34 AM	1	30.188	17

Figure 29: Pulse cycle is typically 17 seconds.

counting methods count the pulses that appear over a specified period of time. Dividing the number of pulses by the counting interval determines the frequency,

A. Count the total number of Pulse Cycles in one trial set, multiply by 5L to get the total volume of water pumped.

B. Count the total number of seconds the pump was on for during one complete trial set. Start from the first second after the first pulse cycle, as this is a cycle now being completed from the previous trial set.

C. Divide [B]; 'the total number of seconds the pump was on for by 17 seconds', as this is the time it takes to achieve one Complete Pulse Cycle (pump 5L). The resulting value is the total number of Pulse Cycle's achieved during the complete trial set. Multiply this value by 5L to get the Numerical Total Volume of Water Pumped.

D. Finally, compare the Actual Total Volume of Water Pumped [A] with the numerically calculated value of [C] to see if the theory works.

[A]	Total number of pulse cycles ->		675		
	Total Volume ->	[675*5L] =	3375	L	
[B]	Total number of seconds the pumps ON				
		[11622-9] =	11613	sec	(-9sec @Start/End)
[C]	Numerical Total Values				
	17sec	[11613/17] =	683.1	Pulse cycles	
		[683*5L] =	3416	L	

Compare Volumes either side:

16sec =	3629 L	18sec =	3226 L

3.4.3 Quantification of Energy Consumption

Energy consumption was calculated from the supply RMS voltage data recorded by the HOBO (CT) Energy Sensor. The Supply Voltage RMS (mV) was converted into watt hours using the following equation:

$$\text{Energy (Wh)} = \left[\frac{\text{RMS mV}}{\text{mV/Amps}}\right] \times I_A \times V_V \times PF \times \text{Time}_{hr} \qquad \text{Eq: [3]}$$

$$\text{Energy (Wh)} = \left[\frac{\text{RMS mV}}{\text{333mV/Amps}}\right] \times 5_A \times 240_V \times 0.95 \times \left(\frac{1\text{hr}}{3600\text{s}}\right)$$

- Specific power factor of the electricity supply = 0.95 (*Dimensionless*)
- The AC output 0.333 Volt per Amps (to changes into mV) -> 0.333V x 1000 = 333mV/A
- The size of the **Current Transformer(CT) = 5A**
- Time in the formula is = (1hr/3600s)
- Pump Operating voltage = 240V

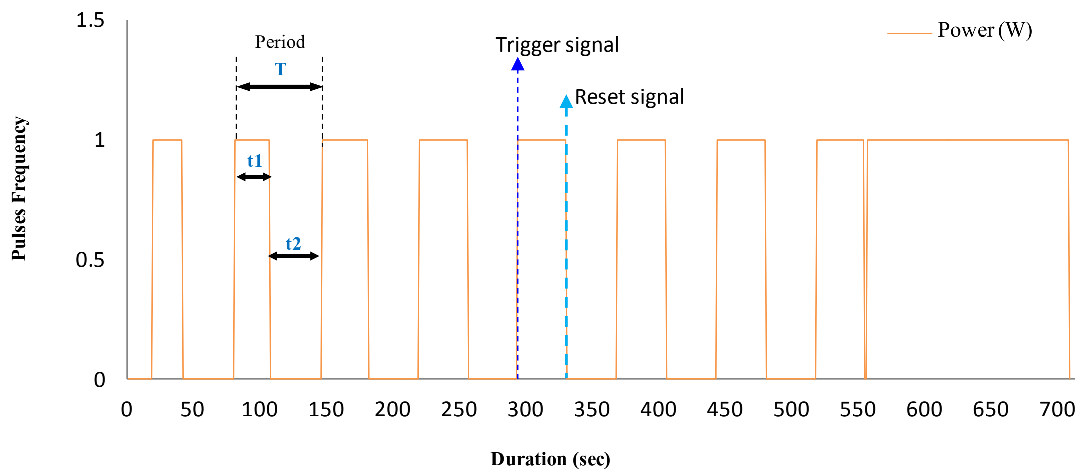


Figure 30: Pump pulse frequency.

The systems energy demand remained constant across all control chips and flowrates, with the pump and air-blowers average energy demand calculated as 102.5 watts and 248.8 watts, or 0.03Wh and 0.07Wh, respectively (Table 7).

Table 7: The GreyFlow systems average energy demand per unit of time (1 sec).

Baseline Flowrate Dataset (L/min)	Pump Energy Demand (Watts)	Air-blower Energy Demand (Watts)	Peak Energy Demand (Watts)
35s (11-17)	102.27	247.92	537.54
35s (6-10)	102.66	250.27	646.89
45s (16-17)	102.30	249.33	578.69
45s (5-9)	102.34	247.99	636.63
45s (11-15)	103.01	248.35	466.95
Avg Demand (W) =	102.5	248.8	573.3
Avg Consumption (kWh)=	0.03	0.07	

3.5 Challenges and Improvements

This section presents the challenges in the data collection process and explains the modifications that were made to the test rigs setup; all other significant challenges that were encountered throughout the project are chronologically presented in Appendix E, Table 10.

The project got off to a bad start. The first day of testing when the GDD stopped working (1 July 2015) saw testing (baseline trials) be delayed by a week after the GW diversion systems pump stop working. To rectify the problem, the pump was removed from the system and brought to the AWWS workshop in Malaga for testing. Testing revealed the float switch.

Figure 31) was faulty (from possibly a faulty batch) and needed to be replaced; the pump was then reinstall and the system was operational by the start of week 2 (6 July 2015).

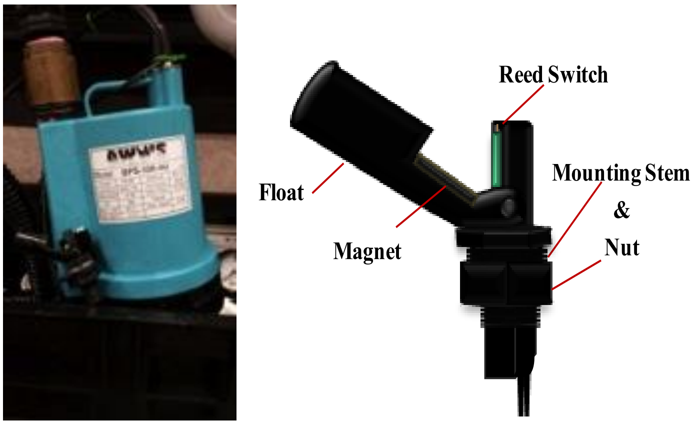


Figure 31: Float switch, level sensor.

However, this operation was short-lived as the float switch needed to be replaced half way through week 3's baseline testing, requiring all baseline trials under the faulty float switch where redone (second data set). A preliminary review of the second dataset showed evidence that the float switch was still experiencing outside interference. Closer inspection of the actual tank, pump, and float switch during pumping cycles revealed the issue appeared to be caused by the incoming turbulent feed water creating a current in the tank on the left as illustrated by

Figure 32.

This occurred just enough so the float switch experienced false starts and stops. To address this problem, the pump was repositioned closer to the inlet port – with the float switch mounted on the opposite side facing away, with the pump acting as a barrier between the inflowing water and the float switch, as shown by the tank one the right in Figure 32.

To achieve this, the length of the pumps discharge pipe as shown in Figure 33 (top left photo) needed to be shortened, resulting in the repositioning of the pump closer to the inlet pipe as shown in Figure 33 (bottom left). A preliminary assessment of the redone third data set showed no outside interference evident in the pumping flow pattern duration times.

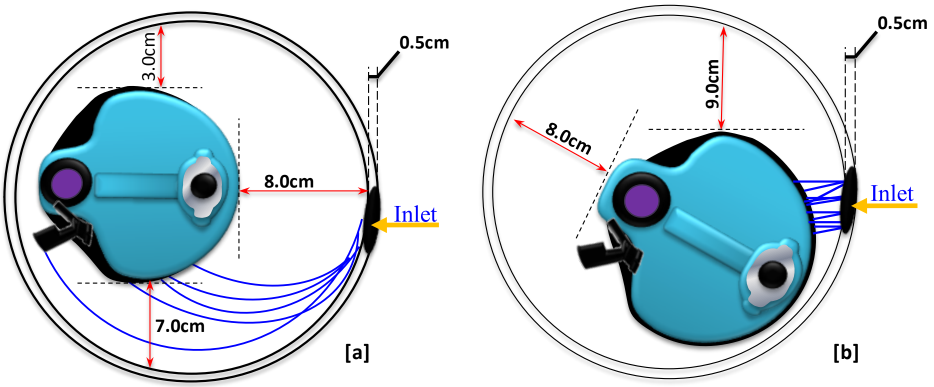


Figure 32: Turbulent flow affecting float switch [a], and new pump position [b].

Figure 33: The pumps positioning in the surge tank, before and after.

Top left: Initial pump position in the surge tank. Bottom left: The pumps new position in the surge tank. Right: AWWS, 100 watt submersible pump and float switch.

CHAPTER 4

4 RESULTS & DISCUSSION

This chapter presents the results obtained during the baseline trials mentioned in the previous chapter. While this chapter is primarily focused on establishing if a relationship exists between energy and volume.

This was achieved through the use of Baseline trials to collect water and energy data over a wide range of flowrates and conducted using both control chips. The aim of the experimental analysis is to investigate and compare the overall performance of both control chips.

This main intention was to investigate whether an alternative way to accurately quantify the volume of GW being captured and reused can be developed, using the pumps own energy consumption to accurately measure the volume of GW being discharged.

4.1 Baseline Flow rate characteristics

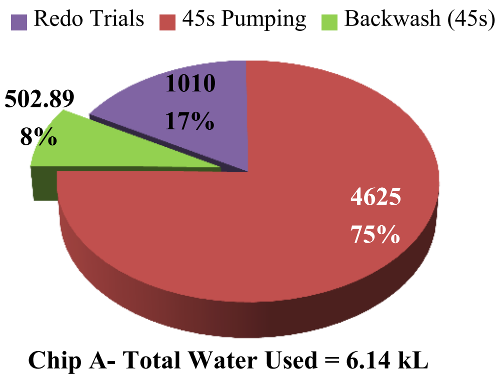
Baseline:

> *A baseline is a reference point or a standard by which things can be measured or compared against. Until a baseline is established for each volumetric flowrate, it is impossible to identify any operational anomalies.*

In order to establish accurate baseline data, the setup conditions of the test rig (once in operation) were kept the same throughout the entire project period, ensuring consistency in the baseline results. The total volume of water used to conduct all baseline trials over the period of this project was approximately 10.32 kL, Figure 34 shows that the total volume of water used in baseline trials conducted with Chip A (seen on the left) was recorded as 6.14 kL, of this 8%(502.9L) is attributed to backwash overflow while 17% (1.11kL) was used in conducting float switch related retrials.

While chip B (displayed on the right) experienced no issues requiring retrials during testing, the total volume of water recorded was 4.18kL, of this 7% (289.2L) was accounted for as overflow during backwashing.

This discrepancy is partially due to the initial float switch malfunctions that occurred at the start of chip A testing, coupled with the fact the project was not initially designed as a comparison project but rather as a product assessment. Consequence Chip A was subject to more baseline trials prior to the addition of chip B, at start of week eight.



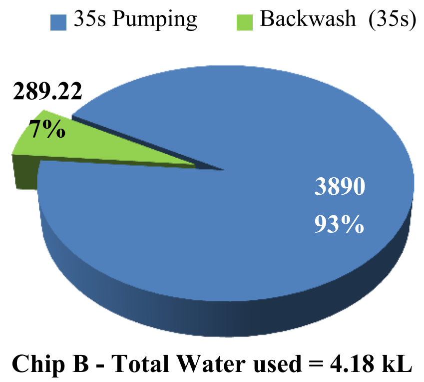
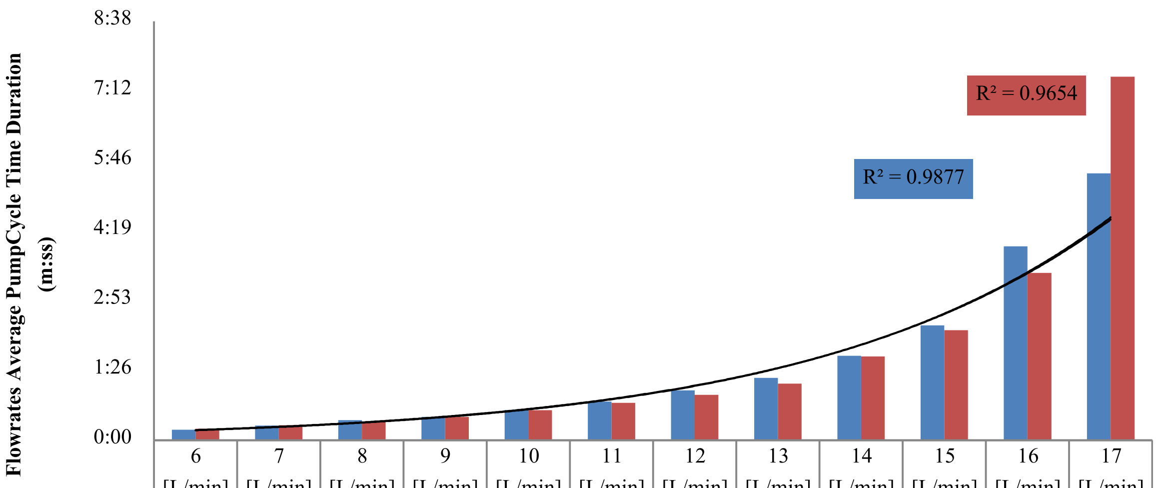


Figure 34: Baseline trials total volume of water per Chip A[LHS], and Chip B[RHS].

The breakdown of water by the different flowrates and by the specific cycle is shown in Appendix G, Table 13. Areas addressed include the volume of water discharged by the pump during normal pumping operations; water lost to the sewer as "overflow" during backwashing (air blower) and all cycle time durations.

The process that was used to evaluate each of the baseline cycle sets was detailed in Chapter 3 (Materials & Methods). The results of each baseline flowrate showed that for each control chip, there was with a specific length of time associated with each flowrates pump cycle, delay cycle, time between pulses and the number of pulses overall.

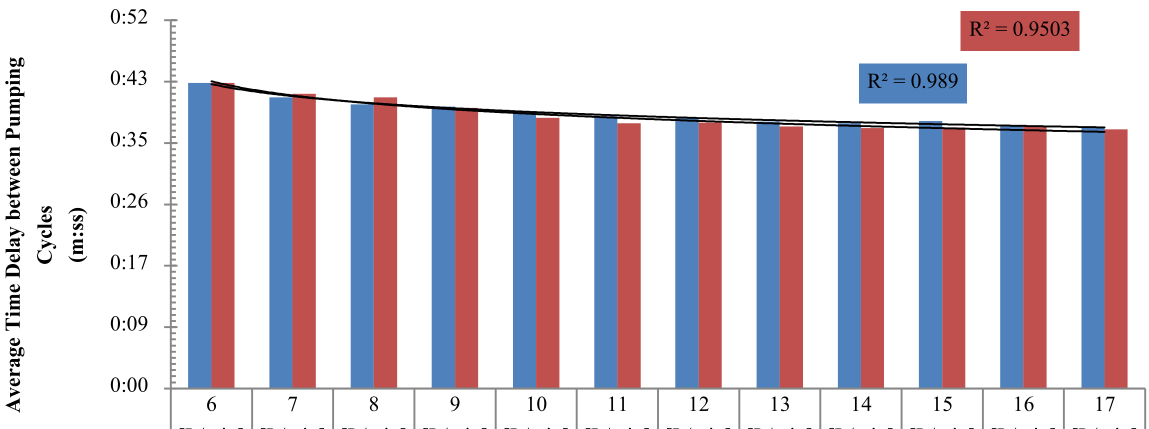
A comparison of both control chips flowrate results, showed significant similarity in the total number of pulse events recorded per flowrate, the time duration per pump cycle and the time delay between each pump cycle. Results shown in Figure 35 indicate the similarity in the pump cycle times are directly proportional to the incoming waters flowrate, while time delay between pump cycles was inversely proportional to incoming flowrate (Figure 36).



	6 [L/min]	7 [L/min]	8 [L/min]	9 [L/min]	10 [L/min]	11 [L/min]	12 [L/min]	13 [L/min]	14 [L/min]	15 [L/min]	16 [L/min]	17 [L/min]
35(s) Chip B	0:13	0:18	0:25	0:29	0:37	0:48	1:02	1:17	1:45	2:22	4:00	5:30
45(s) Chip A	0:14	0:19	0:23	0:29	0:37	0:46	0:56	1:10	1:44	2:16	3:27	7:30

Figure 35: Average pump cycle duration time for a given flowrate.

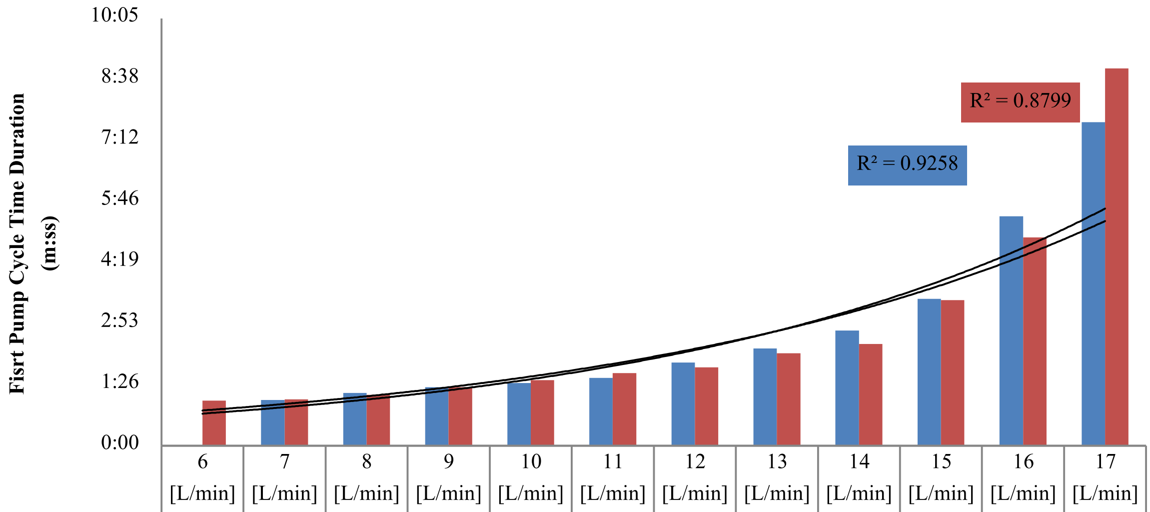
Therefore, the faster the water enters the longer the pump will remain on discharging the necessary volume of water needed to disengage the float switch and the longer the water is supplied the greater the number of pump cycles are completed.



	6 [L/min]	7 [L/min]	8 [L/min]	9 [L/min]	10 [L/min]	11 [L/min]	12 [L/min]	13 [L/min]	14 [L/min]	15 [L/min]	16 [L/min]	17 [L/min]
35(s) Chip B	0:43	0:41	0:40	0:40	0:39	0:38	0:38	0:38	0:37	0:38	0:37	0:37
45(s) Chip A	0:43	0:42	0:41	0:39	0:38	0:37	0:37	0:37	0:37	0:37	0:37	0:37

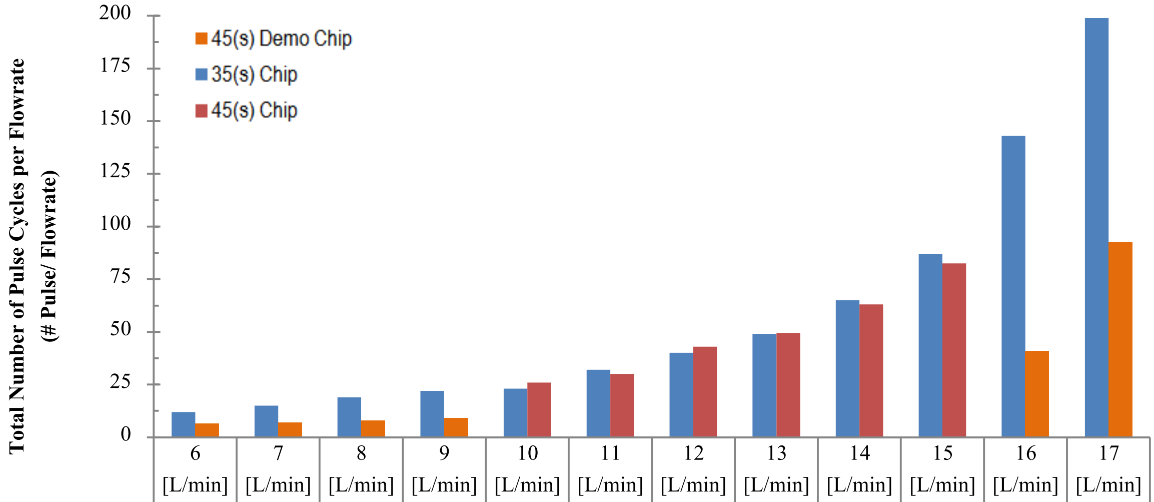
Figure 36: The average time delay between pump cycles for a given flowrate.

Results indicate that the similarity in the shared number of pulse events exhibited by flowrates 10-15 also occur in flowrates 6-9,16 and 17, had they been tested with the full configuration chip A. Therefore, to enable a comparison between the baseline results shown in Figure 37, the results were normalized to account for Demo chip A's smaller cycle sets of only three pump cycles before the backwash (air-blower) is activated. Chip B's baseline results for flowrates 6-9,16 and 17 only contain pump cycles 1,2 and 10 in the creation of an equivalent cycle set results shown in Figure 38.

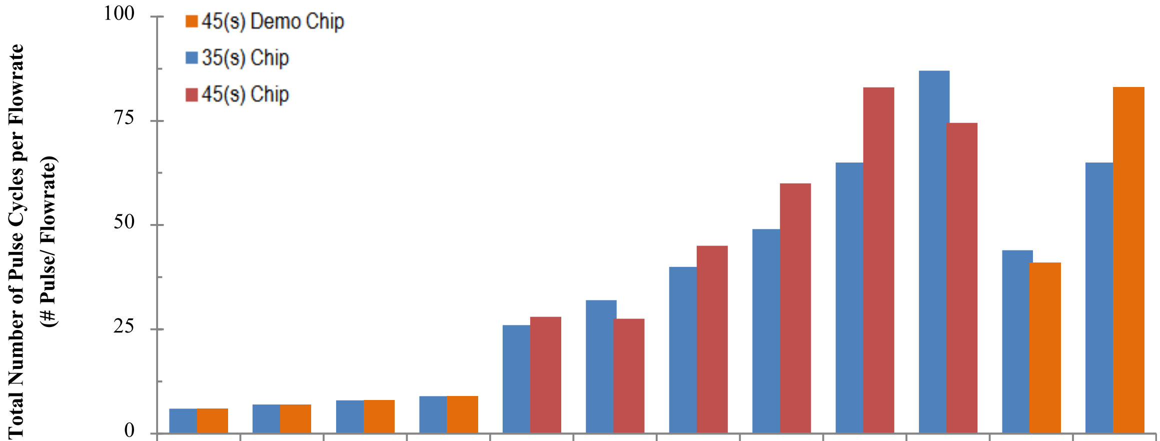


	6 [L/min]	7 [L/min]	8 [L/min]	9 [L/min]	10 [L/min]	11 [L/min]	12 [L/min]	13 [L/min]	14 [L/min]	15 [L/min]	16 [L/min]	17 [L/min]
35(s) Chip B		1:05	1:15	1:23	1:29	1:36	1:58	2:18	2:43	3:28	5:25	7:38
45(s) Chip A	1:04	1:06	1:12	1:23	1:33	1:43	1:51	2:11	2:24	3:26	4:55	8:54

Figure 37: Total number of pulses recorded during each baseline flowrate trial.



	6 [L/min]	7 [L/min]	8 [L/min]	9 [L/min]	10 [L/min]	11 [L/min]	12 [L/min]	13 [L/min]	14 [L/min]	15 [L/min]	16 [L/min]	17 [L/min]
35(s) Chip B	12.0	15.0	19.0	22.0	23.0	32.0	40.0	49.0	65.0	87.0	143.0	199.0
45(s) Chip A	6.5	7.0	8.0	9.0	26.0	30.0	43.0	49.5	63.0	82.5	41.0	92.5



	6 [L/min]	7 [L/min]	8 [L/min]	9 [L/min]	10 [L/min]	11 [L/min]	12 [L/min]	13 [L/min]	14 [L/min]	15 [L/min]	16 [L/min]	17 [L/min]
35(s) Chip B	6.0	7.0	8.0	9.0	26.0	32.0	40.0	49.0	65.0	87.0	44.0	65.0
45(s) Chip A	6.0	7.0	8.0	9.0	28.0	27.5	45.0	60.0	83.0	74.5	41.0	83.0

Figure 38: Total number of pulses normalized to coincide with only three pump cycles.

The breakdown of cycle times by the different flowrates is shown in Appendix G, Table 14.

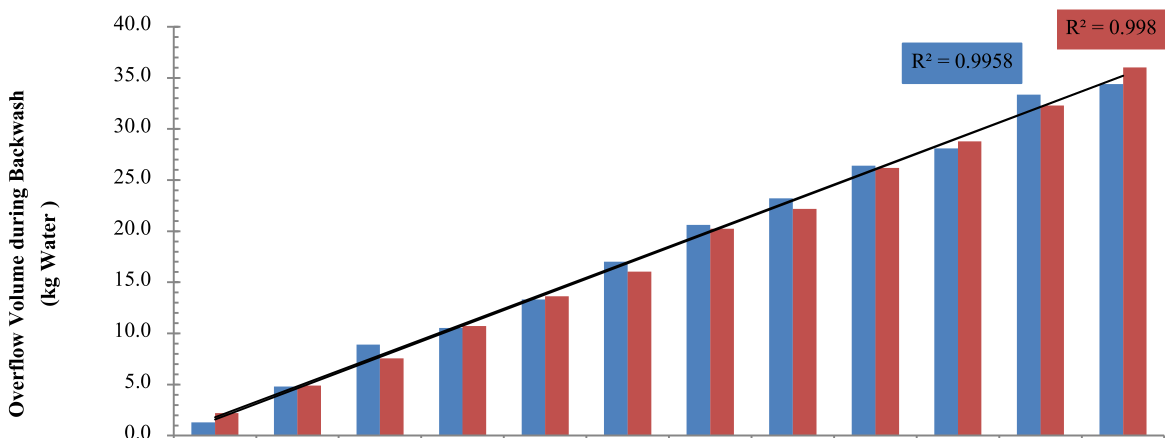
4.2 Self-cleaning (Air-blower) Mechanism: Water Overflow

One of the original project goals outlined in the objectives was to determine what affect an active water supply would have on the system during the backwash cycle.
The GreyFlow GDD contains a fully automated, air assisted self-cleaning mechanism, designed as a form of preventive maintenance to increase the length of time before the filters need to be replaced. The backwash cycle is triggered after a set number of pumping cycles performed (10 or 3 depending on the control chip used) are a clearer understanding of this is given in Appendix B by Figure 45 and Figure 46. By ensuring the filters are maintained regularly through proper backwashing techniques, a reduction in maintenance costs is achieved as well as reducing severity of wear and tear over time. The system works by hydraulically decompressing the filter stack (using an air pump to reverse the flow of water back through the filter media), dislodging any particles trapped (i.e. sand, hair, lint from the filter), discharging directly to the sewer.

The total volume of water discharged to the sewer during a scheduled backwash cycles was shown to be greatly influenced by the ongoing supply water during the backwash cycle with results shown in Figure 39, indicating an increase in the overflow total volume of water lost as a result of backwashing with an active supply flow. It can be noted that the average volume of water lost to the sewer during backwashing is shown to increase noticeably all the way up to and including 12 L/min, with the most dramatically difference exhibited between the lower flowrates – i.e. 6 to 7 L/min, and 8-9 L/min, with percentage increases in overflow total volume ranging from 20% increase to 266% increase as shown by Table 15.

Table 15 compares the backwash overflow volume results of both A and B control chips with an active water supply against the results taken without an active water supply. The results clearly indicate that if the water supply is still active during the air assisted self-cleaning process (backwash cycle), the average volume of water lost in overflow from either control chip will be higher and largely dependent on the water supply flowrate.

A comparative analysis of the overflow volumes revealed no discerning differences between either chips flowrate total volumes, which demonstrates that the only variable to influence the total volume of water being lost to the sewer during a backwash cycle receiving an active water supply, is the velocity of the active water feeding into the system. The reason being, that regardless of the length of time either chip uses during a given pump cycles both chips must carry out the same number of pump cycles (10 cycles) necessary to activate the air-blower. Once activated the air-blower operates for exactly 2 minutes and 31 seconds at which point the incoming flows velocity remains constant, thus controlling the rate at which the sump tank is filled at. Eventually the water level in the sump tank reaching a pressure equilibrium point relative to the interceptor chamber, where upon being filling the interceptor chamber direct the flow out through the reflux valve and down to the sewer. Results presented in Figure 39 provides a comparison of Chip A and B performance relating to the volume of water lost during a backwash cycle grows linearly with values for chip A and chip B being R^2= 0.998 and R^2= 0.9958, respectively.



	6 [L/min]	7 [L/min]	8 [L/min]	9 [L/min]	10 [L/min]	11 [L/min]	12 [L/min]	13 [L/min]	14 [L/min]	15 [L/min]	16 [L/min]	17 [L/min]
35(s) Chip B	1.3	4.8	8.9	10.5	13.3	17.0	20.6	23.2	26.4	28.1	33.4	34.4
45(s) Chip A	2.2	4.9	7.6	10.7	13.6	16.1	20.2	22.2	26.2	28.8	32.3	36.0

Figure 39: The total overflow volume during backwashing under actively supply.

4.3 Energy Consumption

The pumps energy consumption is dictated by the fluid flows velocity and the length of time it's actively supplied.

Results showed tiny fluctuations in the systems average watt demand; nevertheless, the overall energy consumption for the pump and air blower were constant at 0.03Wh and 0.07Wh, respectively (Figure 40).

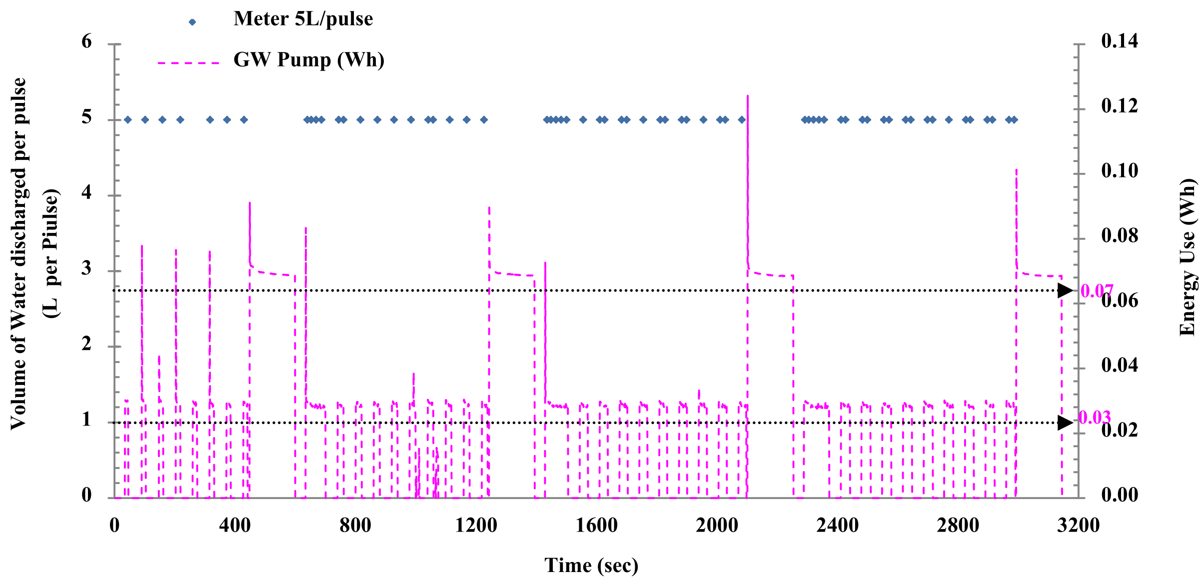


Figure 40: Energy consumption of the pump.

By pairing up the water consumption data with the energy use data, it was possible to accurately calculate the energy use per unit volume of water discharged by the G-Flow system.

4.4 Water and Energy Consumption for Residential Water End Uses

Excluding irrigation, the majority of water use within the home has shown to be from showers, washing machines, and toilets; combined, they comprise the bulk of the average households' annual water consumption. This represents a total of 45 kilolitres per person per year (kL/p/y) based on the findings of the 2008-09 Perth Residential Water Use Study (PRWUS) as replicated by Figure 41 (W.Corp, 2010).

The development of smart metering technology has resulting in more accurate records of end-use water consumption within residential households (Beal, et al., 2011). By examining results from recent residential water end-use studies, a more up to date percentage breakdown of total water consumption was hypothesized (Figure 42). Recent Residential Water Use Studies (RWUS) include Melbourne- MRWUS 2010/12 (Gan & Redhead, 2013), Yarra Valley-YVRWUS 2012 (Athuraliya, et al., 2012), South East Queensland- SEQREUS 2010/11 (Beal & Stewart, 2011) and South Australia SARWUS 2013/14. South Australia's RWUS was excluded from the end-use analysis results and modelling due to differences in end-use breakdown areas.

On first inspection of Table 11 in Appendix G1, with the exclusion of PRWUS, the percentage breakdown for end uses appear relatively similar for showers, washing machines, toilets, tap use, dishwashers, and leaks whilst variation of end-use percentages are evident for irrigation and evaporative air conditions. This could be due to recent end-use studies using high resolution smart meters data that was not available when the PRWUS was undertaken.
However, on closer examination, the actual volume of consumption for each end-use proved quite varied. This variability between volumetric and percentage consumption was the reason both sets of figures where used for comparison.

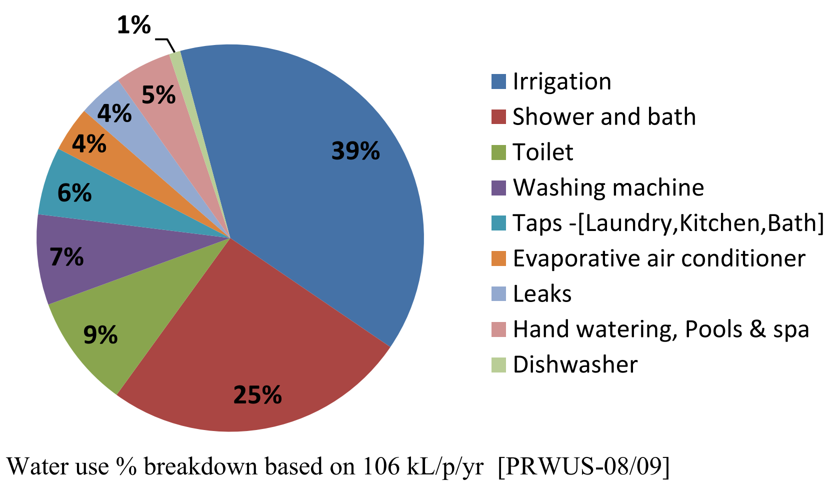
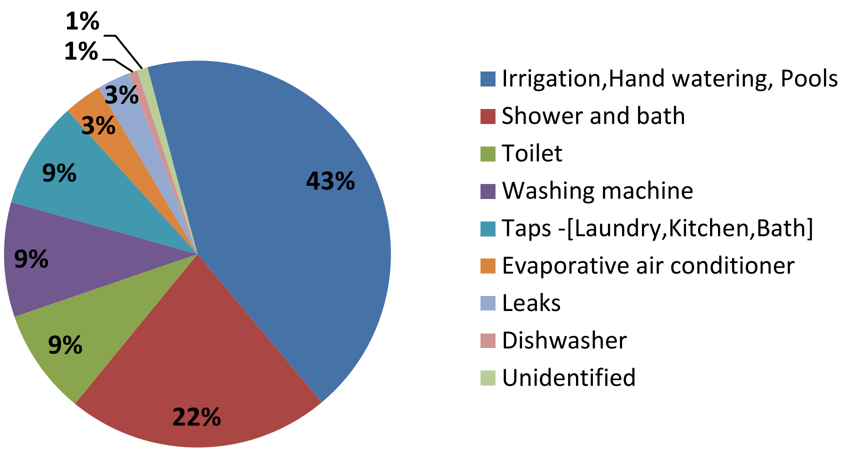


Figure 41: Percentage breakdown of household water use (Replicated PRWUS 2008-09).



Water use % breakdown based on 132 kL/p/yr [ABS, 2015]

Figure 42: Hypothesised percentage breakdown of household water use.

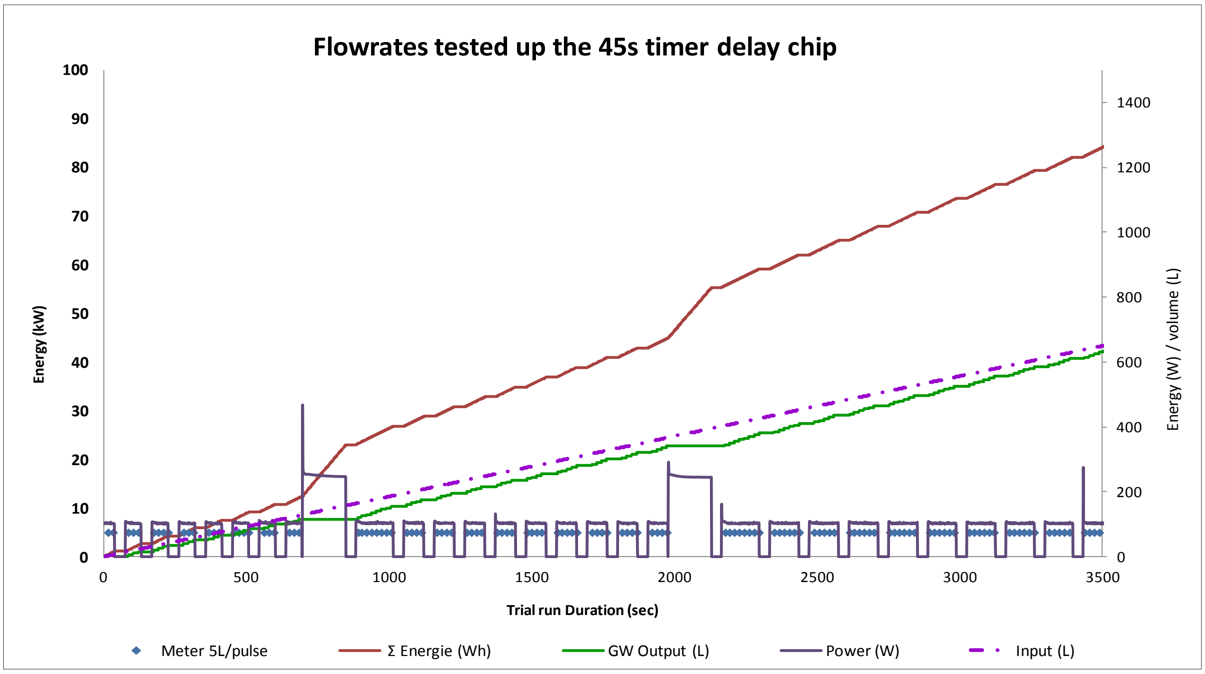


Figure 43: Complete pumping cycle of 35s chip.

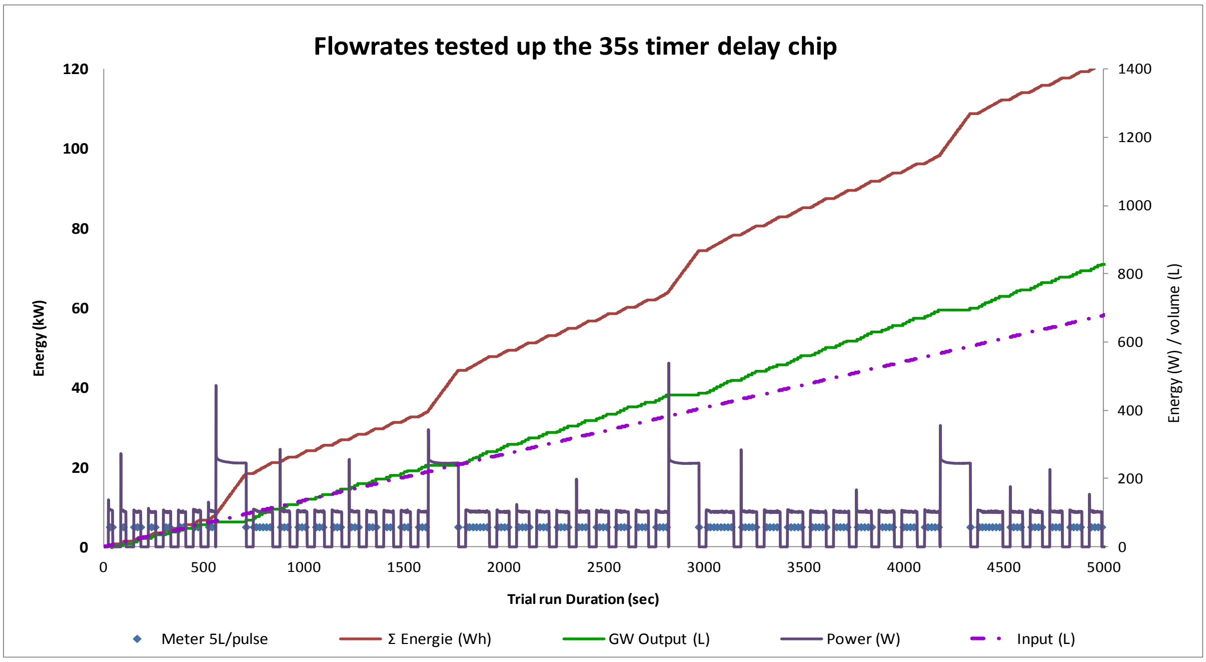


Figure 44: Complete pumping cycle of 45s chip.

CHAPTER 5

5 CONCLUSION

This project sought to: (i) Evaluate whether the energy consumption of a GDD pump could be used to accurately determine the volume of GW being discharged; (ii) establish accurate water and energy use baseline data for comparison; and (iii) monitor the effects associated with filter clogging and time-delay configuration.

This report successfully demonstrated that a relationship clearly exists between the pumps discharge flowrate and energy consumption. The test rig was analysised in terms of its setup, operational performance and water and energy usage.

5.1 KEY FINDINGS

Eastern states Residential Water End-use Studies (RWEUS) are not commutable to WA water consumption habits.

PD water meters are not suitable for any water monitoring application other than for clean water, with the reduction in a meters accuracy directly proportional to the quality of water. Studies showed significant issues when large suspended solid particles were deposited in the gap between the piston/disc and the chamber wall, resulting in over-registration (at medium to high flows) and under-registration (at low flows) and eventually the meter seizing up and coming to a complete stop (Arregui et al, 2005).

5.2 Recommendations

When GDD are installed in homes the water supply will originate from more than one source, which may create a surge in the volume or velocity of water entering the interceptor chambers especially if the water supply is close to the GDD or might have to travel a short distance the reach the system. The effect this might have on the performance of the GDD ability to discharge needs to be investigated.

The water supply for this experiment was clean water free from any major containment. When GDD are installed in homes the resultant greywater generated will contain contaminants, which may take the form of hair, sand, lint to water pollutants. The effect this water would have on the performance of the pressure regulators needs to be investigated.

This study has mainly focused on the hydraulic workings of the device, however to fully understand and mathematically model the device, the physical, mechanical and hydraulic behaviour of the GDD need to be discussed.

5.3 Future Research

Recommendations for the future utilisation of the test rig are as follows;

- Change the float switch, from the current horizontally mounted magnetic reed switch style. To a more durable mechanically activated control switch.

  http://pulsar-pm.com/product-types/level-volume/signal-master.aspx

- The system should be setup as closed loop process, with the test rig connected to a water delivery system. i.e. A storage water tank capable of pumping into the test rig for any given flowrate one complete set (air-blower to air-blower). The water should then passed through the GDS were its then pumped out via the sump pump back to the initial tank.

- A water storage tank should be situated outside of the ETC laboratory. Water is pumped up to the header tank, providing a constant head supply to the experiment.

- The floor of the laboratory has been designed to be drained, however the grid section that allows water to drain is too close to the back into the underground reservoir.

GLOSSARY

Accuracy: The ability of a measuring instrument to indicate values closely approximating the true value of the quantity measured.

Backwashing:
Is a form of preventive maintenance, whereby reversing the flow of water through the filter to dislodged partials i.e. sand, hair, lint will result in the increase in the life span of the filter media and overall system performance. Adhering to a schedule is easily achieved by automating the process through the use of a local programmable logic controller (PLCs).

Blackwater:
Is defined as water that's been mixed with waste discharged from toilets, urinals and bidets. It also includes all the heavily contaminated wastewater from the kitchen and dishwasher, due to the high levels of fats, oils and detergents.

Baseline:
A baseline is a reference point or a standard by which things can be measured or compared against. Until a baseline is established for each volumetric flowrate it is impossible to identify any operational anomalies.

CoP: (The code of practice for the reuse of greywater in Western Australia)

Cycle:
Is an interval of time during which a repeated actions is completed. A cycle set is a series of recurring succession of events that are done by a machine and usually lead back to the starting point.

Filter Cake:
A **filter cake** is formed by the substances that are retained on a **filter**. The **filter cake** grows in the course of **filtration**, becomes "thicker" as particulate matter is being retained. With increasing layer thickness the flow resistance of the **filter cake** increases.

IC (Integrated Circuit) **-** a microprocessor control chip or "Time delay chip"

Primary Treatment – the use of physical processes such as sedimentation to separate the solid wastes from wastewater.

Run-to-completion – Is a scheduling model which typically has a series of task/event in which each task/event will run until it finishes.

Sub-surface Drip Irrigation – a method using GW for irrigation, whereby water is transported beneath the grounds surface through a network of LDPE pipes, distributing directly to the plants root system through 'drippers' (small holes along the pipe). This method ensures minimal human contact with GW.

Wastewater – Specifically referring to "Municipal wastewater" Water that has been used and is adversely affected in quality.

Water Footprint:
The water footprint is a geographical indicator that looks at both direct and indirect freshwater use of a consumer or producer. It is defined as the total volume of freshwater used and polluted in the production of a good or service.

Water Meter: A physical device used in the volumetric billing of fluids, which works by measuring and registering the accumulative volume of water that passes through it. Domestic meter: Standard 20mm meter used mainly for a single residence.

Non-Revenue Water: Water that does not generate revenue for the water utility, including unbilled authorised consumption, apparent losses and real losses.

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6 APPENDIX

A - Approved GDD

Table 8: List of Approved GDD manufactures

Available devices	Approval documents	Contact details
Advanced Waste Water Systems (AWWS) Pty Ltd	• Brand: GreyFlow PS • Model: GreyFlow- 00, PS & US • WaterMark License No WMKT21323	Phone:(08) 9389 7933 sammilani@awws.com.au
Everhard Industries Pty Ltd	• Model: G-Nova Greywater Diversion system • Watermark Licence No: C 40027	www.everhard.com.au Phone: 13 19 26
GreytoGreen Pty Ltd	• Brand: Greytogreen • Model: G2G180 • Approval Number: WMKT21072	www.greytogreen.com Phone: 1800 176 667
Matala Water Technology (Australia) Pty Ltd	• Brand: Greywater Diversion Device • Model: Matala Gatorpro • Watermark Certificate No: WMK 30004	www.gatorpro.com.au
Nylex Corporation Pty Ltd	• Brand: Nylex Greywater Diverta • Model: GYWATDIV65R • Approval Number: PST20057	Phone: 1800 338 105
Plastic Plumbing Supplies Pty Ltd (*trading as Plastic Plumbing & Irrigation Supplies)*	• Brand: Eco-Care • Model: GW W50 • Approval Number: PST20083	Phone: 1300 654 040
PPI Corporation Pty Ltd	• Brand: H2gro • Model: H2gro • Approval Number: WMKT21211	www.h2gro.com.au Phone: (07) 3865 2300
Waterwise Systems Australia Pty Ltd	• Brand: Waterwise Systems • Model: Greywater Gardener 230 • Approval Number: WMKT21219	www.waterwisesystems.com Phone: 1300 133 354
Crocwatch Control Systems Pty Ltd	• Aqua Automation Rain water Management System • Watermark Certified to ATS 5200.477	Phone: 0407 878 700 crocwatch@bigpond.com

B - Pumping Cycles

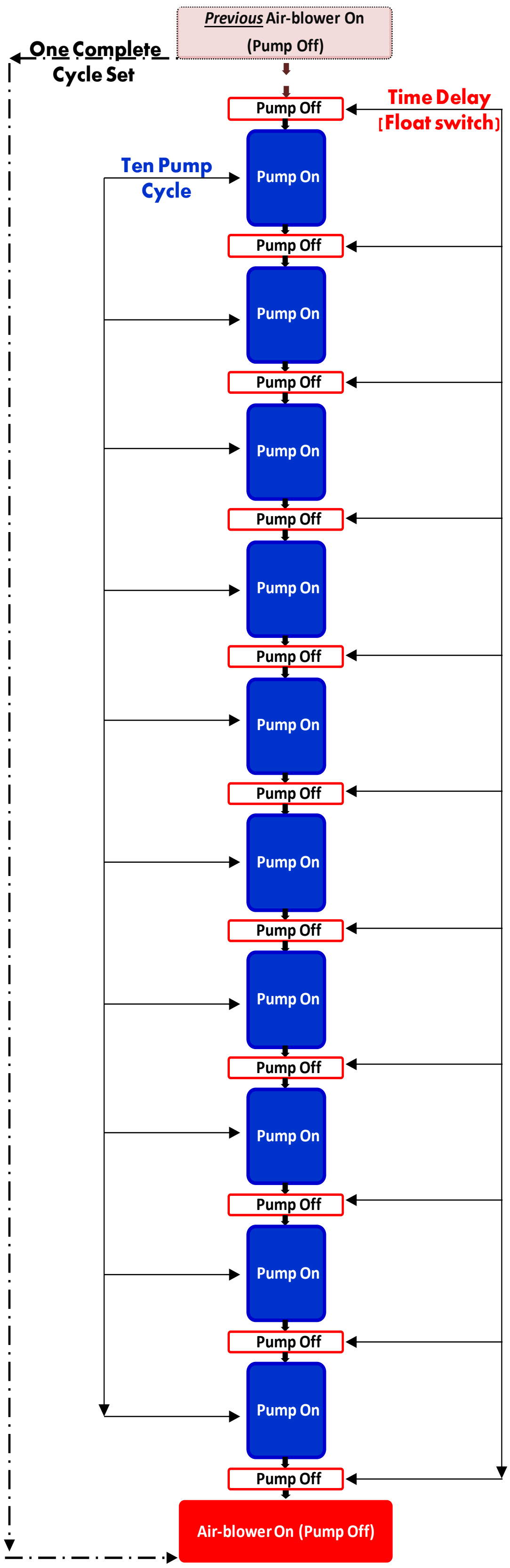


Figure 46: Chip A domestic cycle configuration.

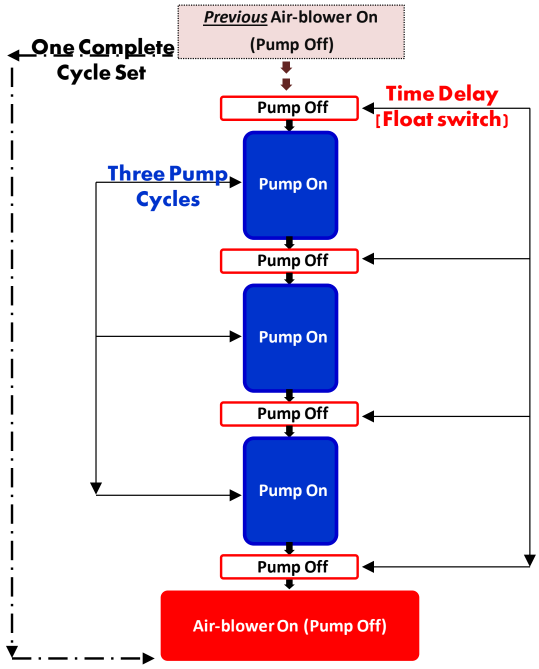
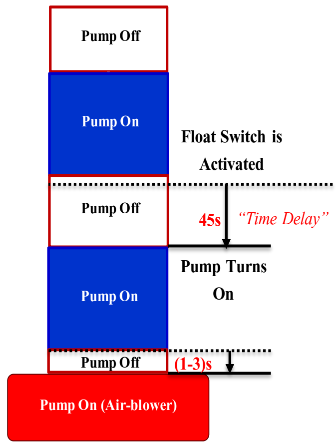


Figure 45: Chip A demo cycle configuration.



C - System Design and Operation

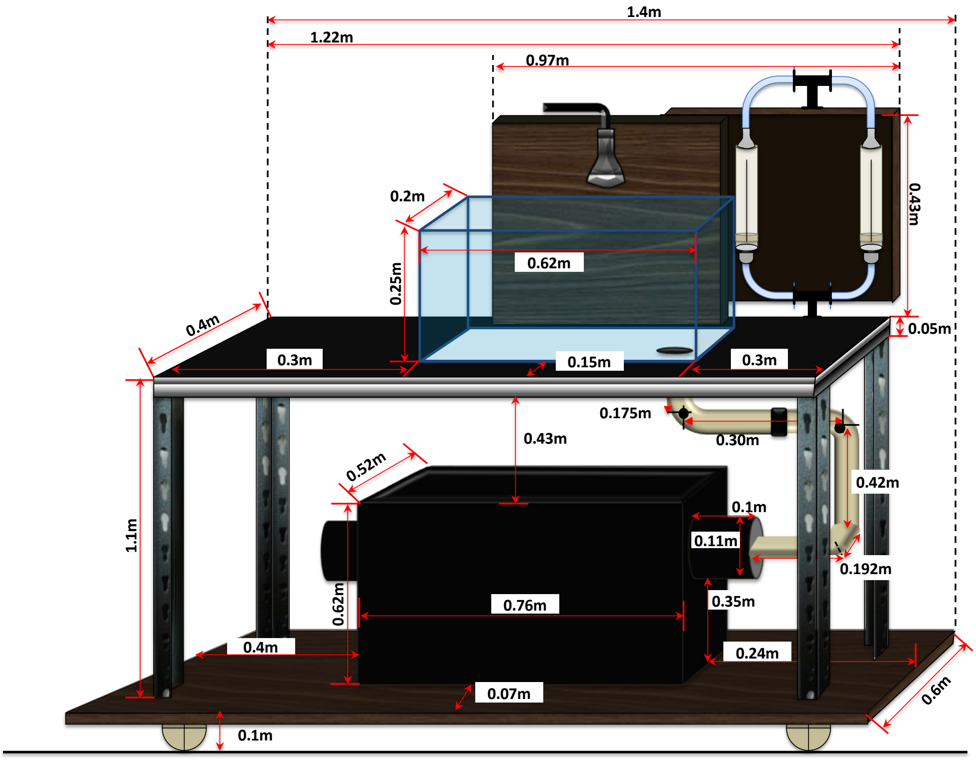


Figure 47: Test rig dimensions.

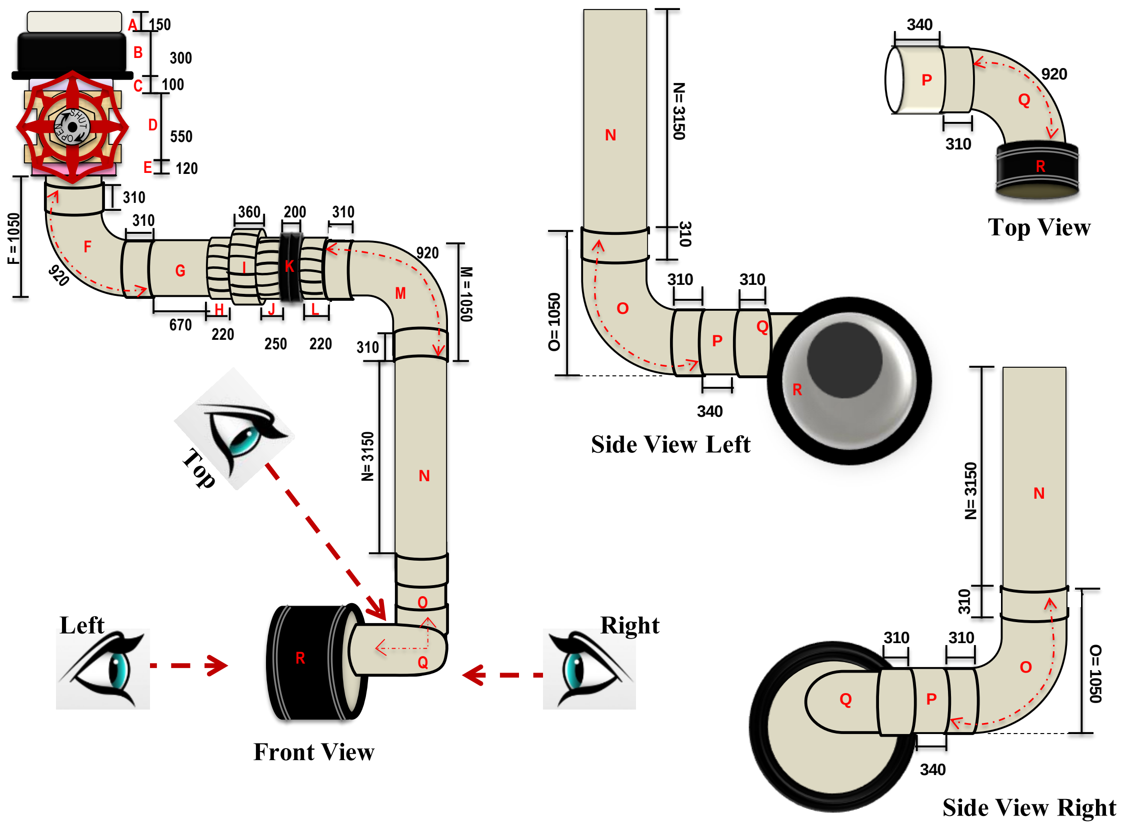


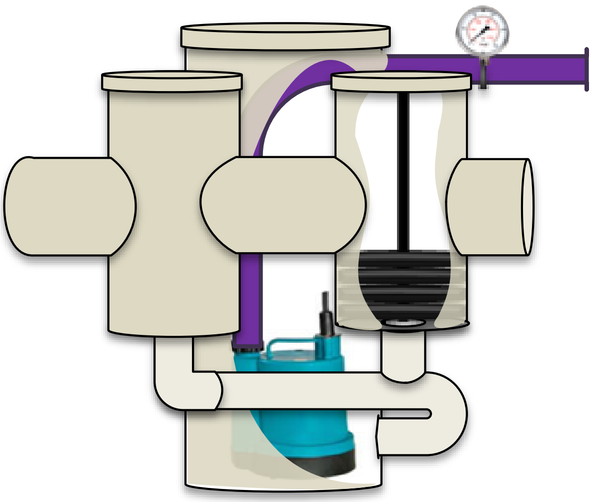
Figure 48: Piping network connecting the rig to the GDD.

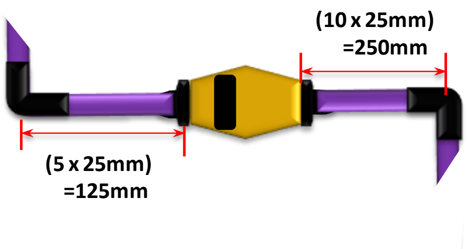
Table 9: Pipe fittings and lengths.

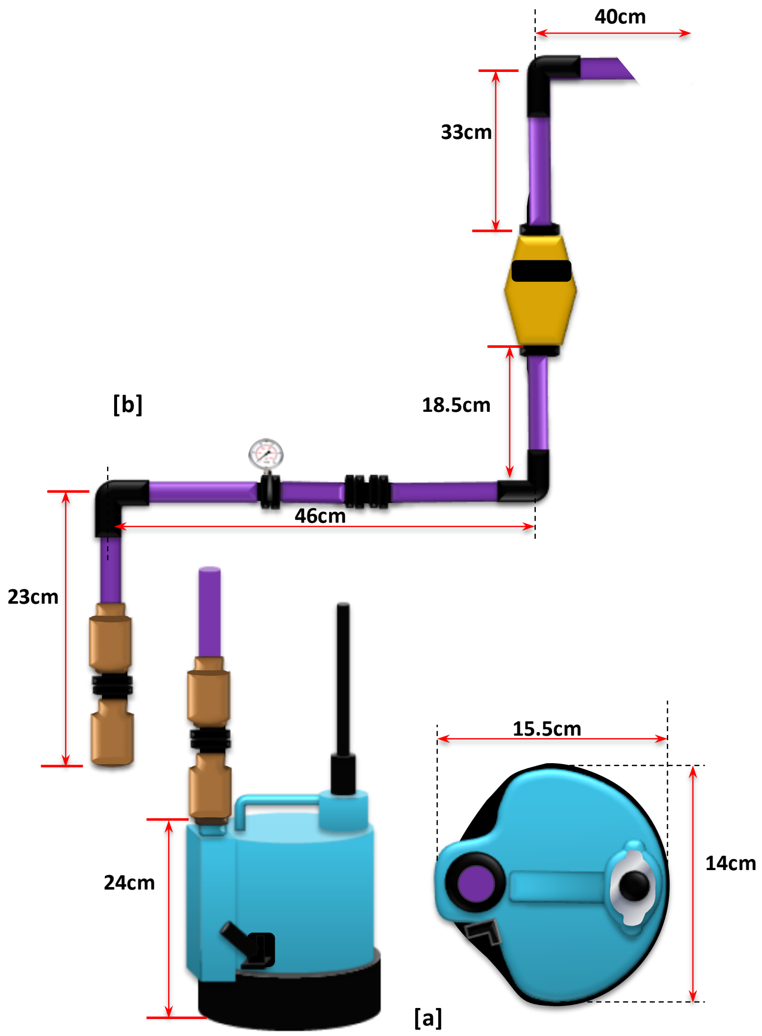
Pipe Fittings	Pipe #	Length (cm)	Le/D
Cleanout Adapter Fitting	A	1.5	
Schedule Adapter	B	3	
Male Adapter	C	1	
Gate Valve	D	5.5	7
Male Pipe Adapter	E	1.2	
Elbow 90°med Sweep	F	10.5	26
Straight Pipe	G	6.7	
Barrel Union	H	2.2	
	I	3.6	
	J	2.5	
Male Poly Nipple Reducing Thread	K	2	
Female Adapter	L	2.2	
Elbow 90°med Sweep	M	10.5	26
Straight Pipe	N	31.5	
Elbow 90°med Sweep	O	10.5	26
Straight Pipe	P	3.4	
Elbow 90°med Sweep	Q	10.5	26
Bush Reducing & Rubber Coupling	R	10	1

Pipe Length =	60.8
(Exc F,M,O,Q)	
[Le/D] =	112
Equivalent= Length	178.3

C1 GDD SPECIFICATION






40cm
33cm
18.5cm
[b]
46cm
23cm
15.5cm
14cm
24cm
[a]

C2 Working Principle Of Positive Displacement Flowmeters

The oscillating or rotating Piston meter consists of a stainless steel housing and a rotating piston as shown in Figure 49. The only moving part in the measuring chamber is the oscillation piston that moves in a circular motion.

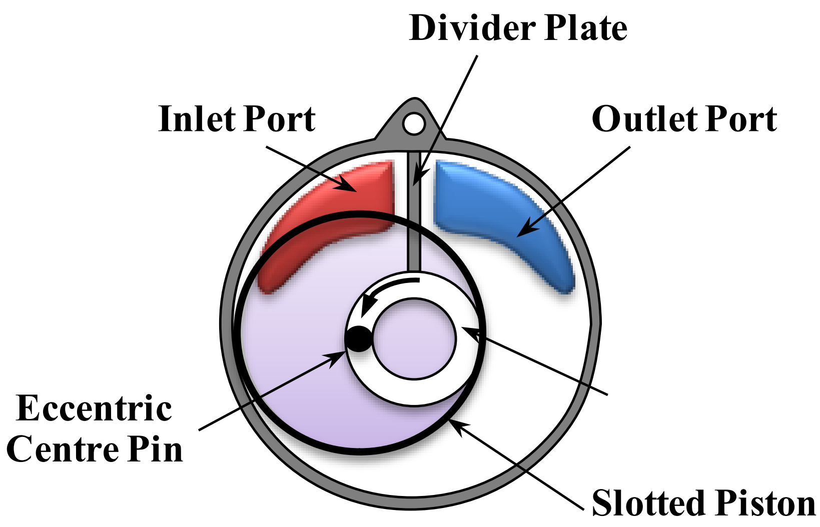


Figure 49: Basic layout of oscillating or rotating piston meter.

Piston meters have a piston that oscillates back and forth as water flows through the meter. A known volume of water is measured for each rotation, and the motion is transmitted to a register through an arrangement of magnetic drive and gear assembly.

To obtain an oscillating motion, movement of the piston is restricted in two ways:

- **First,** the piston is slotted vertically to accommodate a partition plate that is fixed to the chamber. This plate prevents the piston from spinning around its central axis and also acts as a seal between the inlet and outlet ports of the chamber.

- **Secondly,** the piston has a centre vertical pin that confines the piston's movement to a circular track which is part of the chamber. Differential pressure across the meter causes the piston to sweep the chamber wall in the direction of flow, displacing liquid from the inlet to the outlet port in a continuous stream.

The openings for filling and discharging are located in its base and thus in Figure 50(a), Areas 1 and 3 are both receiving liquid from the inlet port (A) and Area 2 is discharging through the outlet port (B).

In Figure 50(b), the piston has advanced and Area 1, which is connected to the inlet port, has enlarged; and Area 2, which is connected to the outlet port, has decreased, while Area 4, is about to move into position to discharge through the outlet port.

In Figure 50(c), Area 1 is still admitting liquid from the inlet port, while Areas 2 and 3 are discharging through the outlet port. In this manner, known discrete quantities of the medium have been swept from the inlet port to the outlet port.

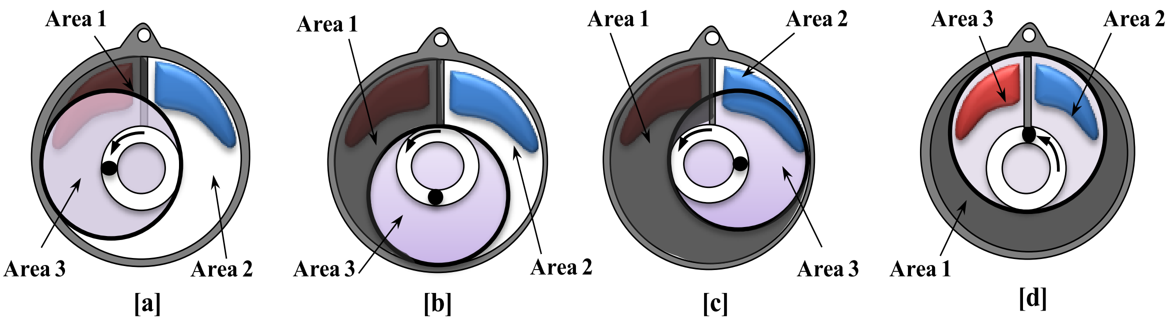


Figure 50: Oscillating or rotating piston meter showing principle of operation.

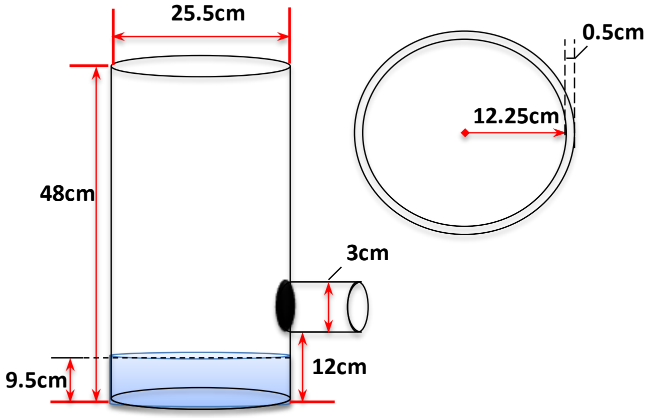
The rotating piston meter is particularly suitable for accurately measuring small volumes and its main advantages are:

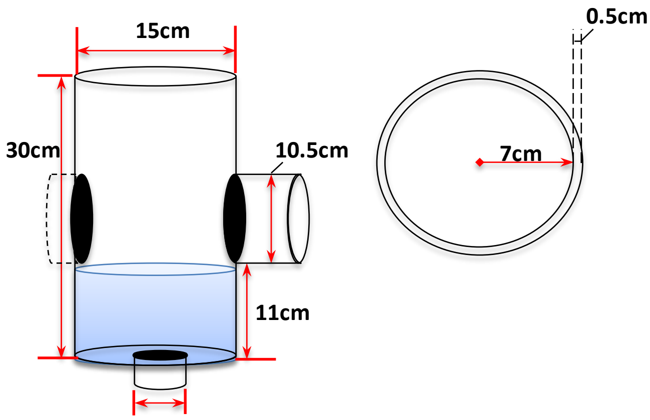
- Accuracy of ± 0.5%; and
- Performance largely unaffected by viscosity (from heating oil to paste).

The main disadvantages of the oscillating piston meter are:

- Affected by water quality and suspended particles ideally suited for clean water.

D - Calculations





Area in the pipe:

$$A(\mathrm{m}^2) = \frac{\pi D^2}{4}$$

Average Velocity in the pipe:

$$\bar{u}\left(\frac{\mathrm{m}}{\mathrm{s}}\right) = \frac{\dot{m}}{\rho A}$$

Reynolds number:

$$N_{Re} = \frac{\rho \bar{u} D}{\mu}$$

Velocity One:

$$\dot{u}_1\left(\frac{\mathrm{m}}{\mathrm{s}}\right) = \frac{\dot{V}}{A_1}$$

Mass & Volumetric flowrates

$$\dot{m}\left(\frac{\mathrm{kg}}{\mathrm{s}}\right) = \rho \dot{V} \rightarrow \rho(\bar{u}A)$$

$$= constant \qquad \dot{V}\left(\frac{\mathrm{m}^3}{\mathrm{s}}\right)$$

$$= \bar{u}A$$

$$\dot{V} = A_1\dot{u}_1 = A_2\dot{u}_2 \rightarrow \left[\pi \frac{D_1^2}{4}\dot{u}_1\right]$$

$$= \left[\pi \frac{D_2^2}{4}\dot{u}_2\right]$$

$$\dot{u}_2\left(\frac{\mathrm{m}}{\mathrm{s}}\right) = \left[\frac{D_1}{D_2}\right]^2 \dot{u}_1$$

Friction Loss:

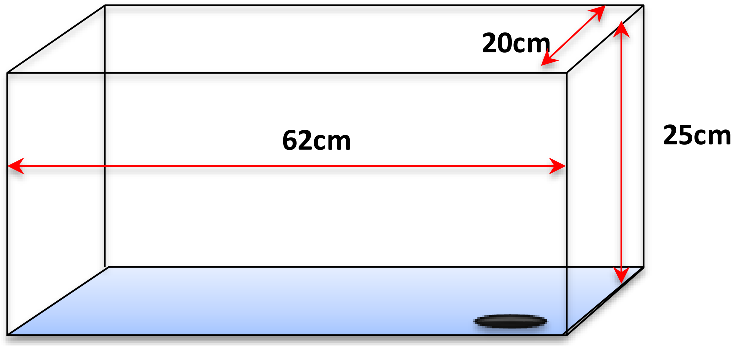
$$E_{f,major}\left(\frac{\mathrm{m}^2}{\mathrm{s}^2}\right) = 2f\left[\frac{\bar{u}^2 L_T}{D}\right]$$

Hydraulic radius:

$$\mathrm{R}_h = \frac{A}{P}$$

Manning Equation (SI units):

$$Q = \left(\frac{1.0}{n}\right) \mathrm{A} \times \mathrm{R}^{\frac{2}{3}} \times \mathrm{S}^{\frac{1}{2}}$$

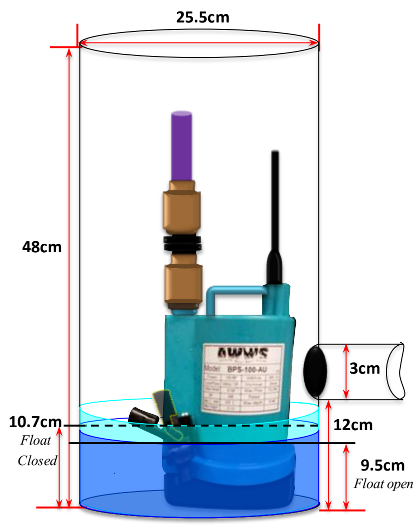


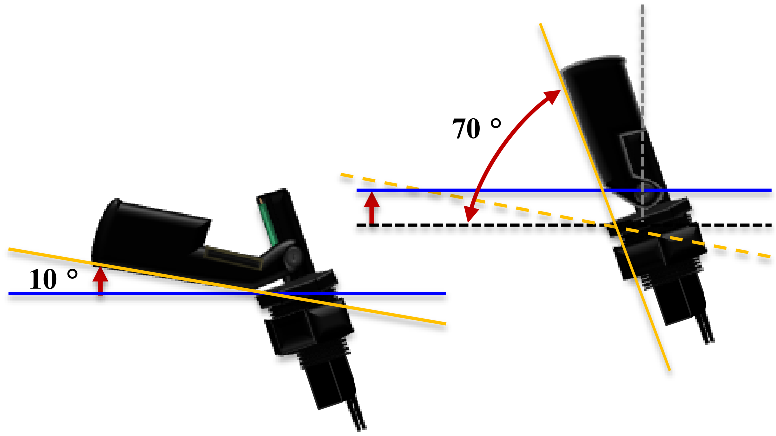
E - Project Timeline and Due Dates.

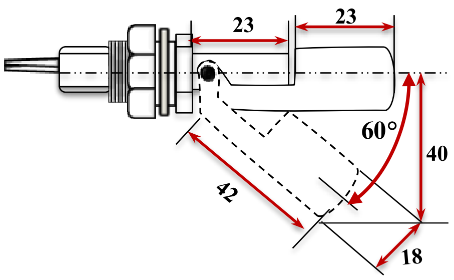
Table 10: Project timeline of important events and issues.

Project Weeks	S2 Weeks	Start Dates		TIMELINE OF THE PROJECTS TASKS & ISSUES
Week 1		30-Jun		Project handover with Ashwin
		1-Jul		Pump stopped working- emailed Sam Milani
		3-Jul		Sam's advised- To take the pump to AWWS WS in Malaga
Week 2		6-Jul		Float switch replaced, pump working again
Week 3		13-Jul	19-Jul	Start the projects "baseline trial" tests
		18-Jul		Replace float switch for 2nd time, **redo trials**
Week 4		21-Jul		Reposition pump in the surge tank, to block float switch , **redo trials**
		22-Jul		Sam Milani returned to Australia (NA till 28/7)
Week 5	Week 1	29-Jul		Meeting with supervisors Martin and Stewart
Week 6	Week 2	3-Aug	9-Aug	Finished **"baseline trials"** ready to start filter clogging tests
		4-Aug		Emailed Sam requesting a meeting now back in Australia
Week 7	Week 3	12-Aug		Sam confirmed date, meeting scheduled for 17th August
Week 8	Week 4	17-Aug		Initial meeting with Sam milani owner of AWWS about my thesis and his GDD Outcome : Changes to the rigs IC control chips (new time delay, new chip)
		19-Aug		Meeting with martin to discuss the new IC control chip given by Sam. Outcome: Told to redo baseline trials with new chip
		21-Aug		Hand in project proposal
Week 9	Week 5	25-Aug		Phone meeting with Stewart to discuss options to incorporate the data already collected into the projects scope
		25-Aug		Emailed Martin & Stewart with solution – Do comparison of both IC chips
		26-Aug		Emailed Sam with comparison solution, requested any RD on the new chip Outcome: No RD done, no information available
		27-Aug		All parties notified of changes new start date for additional "baseline trail"
Week 10	Week 6	31-Aug	6-Sep	Start new control chips "baseline trials"
Week 11	Week 7	7-Sep	13-Sep	cont.., new control chips "baseline trials" tests -(raw data not completely analysed)
Week 12	Week 8	18-Sep		Progress Report Due
Week 13 **Week 14** **Week 15** **Week 16**	Week 9 Week 10 Week 11 Week 12	**19-Sep**		Injure back at the test rig
		21-Sep		Spinal X-rays: Injury-> **Anterolisthesis** due to existing bilateral paras defects. Outcome: 6 weeks ban from working with the test rig due to the rigs low design which requires bending Solution: Went 3 times a week for treatment, reducing the 6 week ban to 5
Week 17	Week 13	**19-Oct**		Return to the test rig to start filter clogging tests- under time constraints
		19-Oct	23-Oct	HOBO device not working- tried to fixing it myself , emailed David Goodfield
Week 18	Week 14	26-Oct	29-Oct	Swapped HOBO device with 3 different spares none working
		30-Oct		David contacted the manufactures of the HOBO U30, got it working again.
Week 19	Week 15	2-Nov		Start filter clogging testing (due to time constraints, testing was not the original method chosen) and results failed to produce anything
Week 20	Week 16	9-Nov		Analysis all new data results - Finish Thesis report & prepare the presentation
		13-Nov		Present project results to assessors– **Do Presentation**

F - Float switch Issues







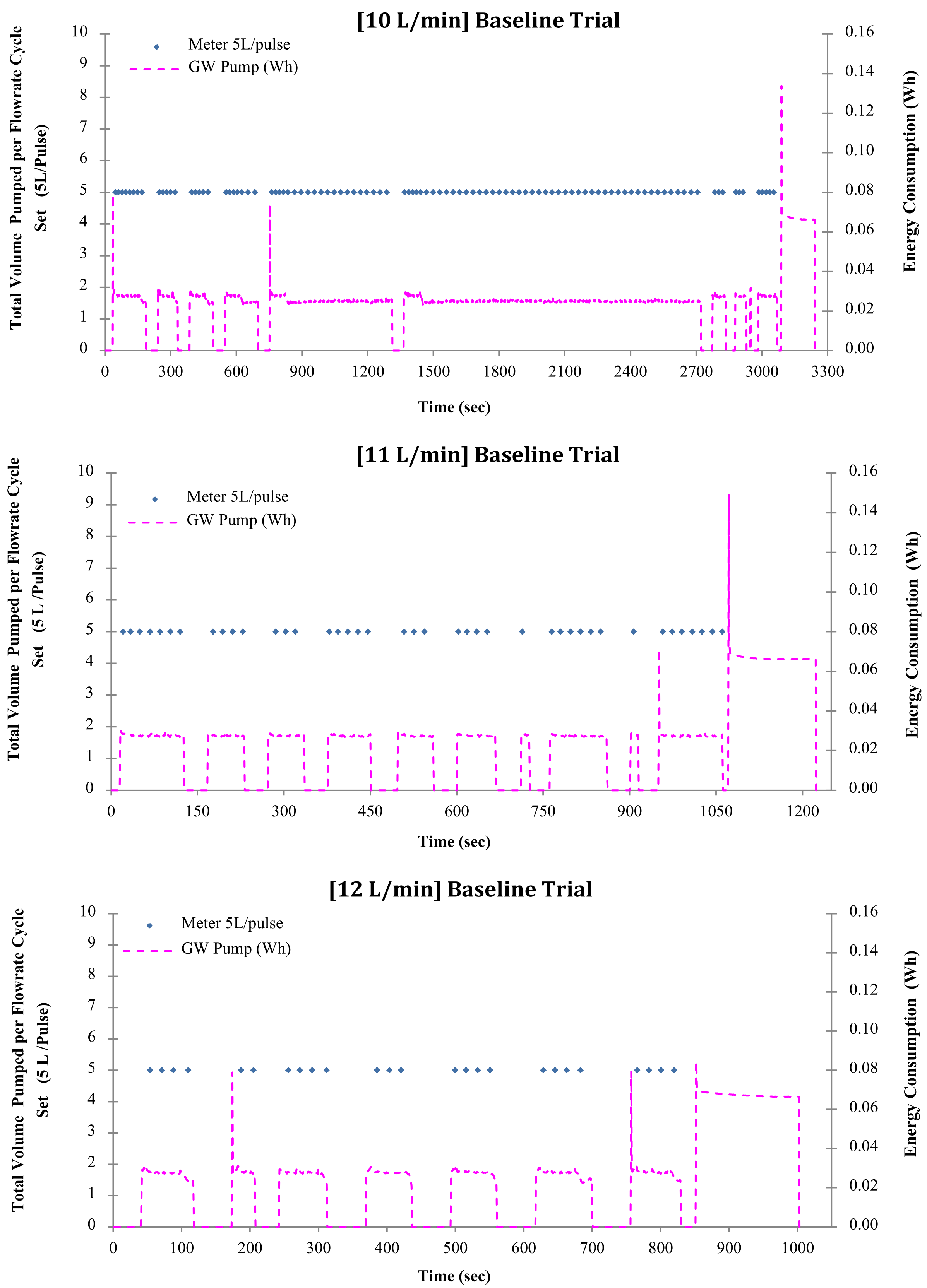


Figure 51: Baseline trails affected by float switch issues energy use.

G - Residential Water End Use Studies

Table 11: Comparison between past RWEUS.

	PRWUS	MRWUS		YVRWUS	SEQREUS			PRWUS	MRWUS		YVRWUS	SEQREUS		
Household = 2.6 people	2008/09	2010[W]	2012[S]	2012[S]	2010[W]	2010/11[S]	2011[W]	2008/09	2010[W]	2012[S]	2012[S]	2010[W]	2010/11[S]	2011[W]
	Total Use %	**Total Use %**		**Total Use %**	**Total Use %**			**Water Use L/hh/d**	**Water Use L/hh/d**		**Water Use L/hh/d**	**Water Use L/hh/d**		
Irrigation	39%	3.3%	18.3%	15.5%	5.0%	3.8%	4.6%	292.1	11.6	80.9	52.1	18.5	11.8	19.1
Shower and bath	25%	31.9%	28.1%	25.4%	31.3%	30.4%	35.7%	192.3	112.3	124.2	85.3	116.0	94.6	148.4
Toilet	9%	17.5%	13.1%	14.8%	16.5%	18.4%	16.9%	71.2	61.6	57.9	49.7	61.2	57.3	70.2
Washing machine	8%	19.7%	13.0%	14.3%	21.0%	21.1%	21.9%	57.0	69.3	57.5	48.0	77.8	65.7	91.0
Taps -[Laundry, Kitchen, Bath]	6%	16.4%	16.3%	15.7%	19.0%	21.9%	17.3%	42.7	57.7	72.0	52.8	70.4	68.2	71.9
Evaporative air conditioner	4%	0.6%	5.2%	10.3%	0.0%	0.0%	0.0%	28.5	2.1	23.0	34.6	0.0	0.0	0.0
Leaks	4%	5.8%	4.3%	1.6%	6.0%	3.2%	2.1%	28.5	20.4	19.0	5.4	22.2	10.0	8.7
Hand watering, Pools & spa	5%	0.0%	0.5%	0.4%	0.0%	0.0%	0.0%	37.0	0.0	2.2	1.3	0.0	0.0	0.0
Dishwasher	1%	1.2%	0.8%	0.8%	2.0%	1.5%	1.5%	7.1	4.2	3.5	2.7	7.4	4.7	6.2
Unidentified	0 %	3.6%	0.4%	1.2%	0.0%	0.0%	0.0%	0.0	12.7	1.8	4.0	0.0	0.0	0.0
per capita water uses (L/p/d)	397.3	114.0	145.0	137.0	145.3	125.3	144.9							
Household water uses (L/hh/d)	758.9	352.0	442.0	336.0	370.7	311.3	415.6							

G1 FLOWRATE IDEAL SHOWER TIMES

Table 12: Ideal Shower durations, based on flowrate cycle set times.

Total No Pulse per Cycle Set	Total Volume Pumped (L)	Ideal Shower Duration for all Water Flowrates	5 min	6 min	7 min	8 min	9 min	10 min	11 min	12 min	13 min	14 min	15 min	16 min	17 min	18 min	19 min	20 min	21 min	22 min	23 min	24 min	25 min	26 min	27 min	28 min	29 min	30 min	45 min	59 min
7	35	**6 L/min**	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144	150	156	162	168	174	180	270	354
15	75	**7 L/min**	35	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147	154	161	168	175	182	189	196	203	210	315	413
19	95	**8 L/min**	40	48	56	64	72	80	88	96	104	112	120	128	136	144	152	160	168	176	184	192	200	208	216	224	232	240	360	472
22	110	**9 L/min**	45	54	63	72	81	90	99	108	117	126	135	144	153	162	171	180	189	198	207	216	225	234	243	252	261	270	405	531
26	130	**10 L/min**	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	450	590
32	160	**11 L/min**	55	66	77	88	99	110	121	132	143	154	165	176	187	198	209	220	231	242	253	264	275	286	297	308	319	330	495	649
40	200	**12 L/min**	60	72	84	96	108	120	132	144	156	168	180	192	204	216	228	240	252	264	276	288	300	312	324	336	348	360	540	708
49	245	**13 L/min**	65	78	91	104	117	130	143	156	169	182	195	208	221	234	247	260	273	286	299	312	325	338	351	364	377	390	585	767
65	325	**14 L/min**	70	84	98	112	126	140	154	168	182	196	210	224	238	252	266	280	294	308	322	336	350	364	378	392	406	420	630	826
87	435	**15 L/min**	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	675	885
143	715	**16 L/min**	80	96	112	128	144	160	176	192	208	224	240	256	272	288	304	320	336	352	368	384	400	416	432	448	464	480	720	944
199	995	**17 L/min**	85	102	119	136	153	170	187	204	221	238	255	272	289	306	323	340	357	374	391	408	425	442	459	476	493	510	765	1003

Ideal Shower durations, based on specific flowrates and cycle set time Chip B(35s).

H - Baseline Data

Table 13: Completed overview of flowrate baseline results.

Baseline Flowrate Sets	Total No of Pulse Events per Set		Total Discharged Volume		Time Duration per Full Cycle set		Baseline Flowrate Ratio (Vol per time)		Baseline Set Discharge Flowrate	
(L/min)	(Pulse)	(Pulse)	(L)	(L)	(sec)	(sec)	(L/s)	(L/s)	(L/min)	(L/min)
6	6.5	7.0	32.5	35	367.5	599.0	0.088	0.058	5.31	3.51
7	7.0	15.0	35	75	380.0	795.0	0.092	0.094	5.53	5.66
8	8.0	19.0	40	95	394.0	859.0	0.102	0.111	6.09	6.64
9	9.0	22.0	45	110	414.7	892.0	0.109	0.123	6.51	7.40
10	26.0	23.0	130	115	970.5	966.0	0.134	0.119	8.04	7.14
11	30.0	32.0	150	160	1034.0	1060.0	0.145	0.151	8.70	9.06
12	43.0	40.0	215	200	1276.0	1205.0	0.168	0.166	10.11	9.96
13	49.5	49.0	247.5	245	1371.0	1359.0	0.181	0.180	10.83	10.82
14	63.0	65.0	315	325	1602.0	1630.0	0.197	0.199	11.80	11.96
15	82.5	87.0	412.5	435	1943.5	2014.0	0.212	0.216	12.73	12.96
16	41.0	143.0	205	715	972.0	3004.0	0.211	0.238	12.65	14.28
17	92.5	199.0	462.5	995	1865.5	3950.0	0.248	0.252	14.88	15.11
Totals =	458.0	701.0	2290.0	3505.0	12590.7	18333.0	1.9	1.9	113.2	114.5
[excl 16,17]=	324.5	359.0	1622.5	1795.0	9753.2	11379.0	1.4	1.4	85.6	85.1

H1 COMPLETE BASELINE DATASET

Table 14: The flow cycle breakdown comparison between chip A and chip B.

Flowrate(L/min)		Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5		Cycle 6		Cycle 7		Cycle 8		Cycle 9		Cycle 10		Air Blower	*Pump On*	*Pump Off*
***Chip B* - 6L**					0:33	0:11	0:46	0:12	0:45	0:13	0:43	0:14	0:42	0:14	0:42	0:14	0:42	0:13	0:43	0:13	0:08	2:30	0:13	0:43
***Chip A* - 6L**	0:37	1:04	0:43	0:14	0:43	0:14															0:06	2:32	0:14	0:43
7L	0:36	1:05	0:41	0:19	0:41	0:19	0:41	0:19	0:41	0:18	0:41	0:19	0:41	0:18	0:42	0:18	0:42	0:18	0:42	0:18	0:06	2:30	0:18	0:41
7L	0:36	1:06	0:42	0:19	0:41	0:18															0:06	2:31	0:19	0:42
8L	0:36	1:15	0:40	0:26	0:40	0:26	0:40	0:26	0:40	0:26	0:40	0:24	0:41	0:26	0:40	0:26	0:40	0:26	0:40	0:25	0:05	2:31	0:25	0:40
8L	0:36	1:12	0:41	0:23	0:41	0:23															0:05	2:31	0:23	0:41
9L	0:35	1:23	0:40	0:29	0:39	0:30	0:39	0:29	0:40	0:29	0:40	0:29	0:39	0:29	0:40	0:28	0:40	0:29	0:40	0:29	0:04	2:31	0:29	0:40
9L	0:36	1:23	0:39	0:29	0:40	0:29															0:05	2:31	0:29	0:39
10L	0:35	1:29	0:39	0:37	0:39	0:37	0:38	0:38	0:39	0:38	0:39	0:36	0:39	0:38	0:39	0:37	0:40	0:38	0:39	0:37	0:03	2:31	0:37	0:39
10L	0:35	1:33	0:37	0:37	0:38	0:37	0:38	0:38	0:39	0:38	0:38	0:37	0:38	0:38	0:38	0:37	0:38	0:37	0:39	0:36	0:03	2:31	0:37	0:38
11L	0:36	1:36	0:38	0:48	0:38	0:49	0:38	0:48	0:39	0:48	0:38	0:48	0:39	0:48	0:38	0:48	0:38	0:47	0:39	0:48	0:03	2:30	0:48	0:38
11L	0:35	1:43	0:37	0:46	0:37	0:47	0:37	0:47	0:38	0:45	0:38	0:46	0:37	0:46	0:38	0:46	0:37	0:46	0:37	0:46	0:02	2:31	0:46	0:37
12L	0:37	1:58	0:38	1:01	0:38	1:02	0:38	1:02	0:38	1:01	0:38	1:02	0:38	1:01	0:38	1:01	0:38	1:02	0:38	1:02	0:02	2:31	1:02	0:38
12L	0:35	1:51	0:37	0:56	0:38	0:56	0:38	0:56	0:37	0:57	0:38	0:56	0:38	0:57	0:37	0:56	0:37	0:57	0:37	0:56	0:02	2:31	0:56	0:37
13L	0:36	2:18	0:37	1:18	0:38	1:19	0:37	1:17	0:38	1:18	0:38	1:17	0:37	1:15	0:38	1:16	0:38	1:17	0:37	1:17	0:02	2:31	1:17	0:38
13L	0:35	2:11	0:37	1:10	0:37	1:10	0:37	1:10	0:37	1:11	0:37	1:10	0:37	1:10	0:37	1:10	0:37	1:10	0:36	1:10	0:01	2:31	1:10	0:37
14L	0:36	2:43	0:38	1:44	0:37	1:45	0:38	1:45	0:37	1:45	0:37	1:45	0:37	1:46	0:37	1:43	0:38	1:45	0:37	1:43	0:03	2:30	1:45	0:37
14L	0:35	2:24	0:37	1:45	0:36	1:45	0:37	1:45	0:37	1:43	0:37	1:44	0:37	1:43	0:36	1:43	0:37	1:43	0:36	1:43	0:02	2:30	1:44	0:37
15L	0:36	3:28	0:37	2:24	0:38	2:24	0:38	2:25	0:37	2:24	0:38	2:22	0:37	2:22	0:38	2:18	0:38	2:20	0:38	2:19	0:02	2:31	2:22	0:38
15L	0:35	3:26	0:37	2:15	0:37	2:16	0:37	2:16	0:37	2:16	0:36	2:15	0:37	2:17	0:37	2:16	0:37	2:16	0:36	2:16	0:02	2:31	2:16	0:37
16L	0:36	5:25	0:37	3:56	0:37	3:21	0:37	3:25	0:37	3:25	0:37	4:14	0:36	4:25	0:37	4:30	0:37	4:27	0:37	4:15	0:01	2:31	4:00	0:37
16L	0:36	4:55	0:37	3:27	0:37	3:27															0:01	2:31	3:27	0:37
17L	0:36	7:38	0:37	5:37	0:37	5:19	0:37	5:28	0:36	5:37	0:37	5:34	0:37	5:42	0:36	5:37	0:37	5:35	0:37	5:03	0:02	2:30	5:30	0:37
17L	0:36	8:54	0:36	7:27	0:37	7:40															0:01	2:31	7:30	0:37

H2 Flowrate Backwash Overflow Volume

Table 15: Comparison of backwash overflow with and without active water supply.

Baseline Flowrate Sets (L/min)		WELS Efficiency Rating	Water supplied Overflow (kg) No Chip A	Yes Chip A	Yes Chip B	Discharge flowrate Ratio (L/s)	(L/s)	Overflow volume % Increase %	%
	6 [L/min]	< 3 Stars	**3.0**	2.20	1.3	0.015	0.009		
> 7.5	7 [L/min]			4.89	4.8	0.032	0.032	122%	266%
	8 [L/min]	3 Stars	**7.0**	7.57	8.9	0.050	0.059	55%	86%
7.5 > 9	9 [L/min]			10.73	10.5	0.071	0.070	42%	18%
	10 [L/min]			13.64	13.3	0.090	0.088	27%	26%
	11 [L/min]	2 Stars		16.06	17.0	0.106	0.113	18%	28%
9 > 12	12 [L/min]		**19.0**	20.25	20.6	0.134	0.137	26%	21%
	13 [L/min]			22.17	23.2	0.147	0.154	10%	13%
	14 [L/min]			26.18	26.4	0.173	0.175	18%	14%
	15 [L/min]	1 Stars		28.80	28.1	0.191	0.186	10%	6%
12 > 16	16 [L/min]		**27.0**	32.29	33.4	0.214	0.221	12%	19%
16 >	17 [L/min]	0 Stars		36.02	34.4	0.239	0.228	12%	3%

H3 Filter Clogging Results

Baseline 9 [L/min]		Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5		Cycle 6		Cycle 7		Cycle 8		Cycle 9		Cycle 10		Air-Blower	Average Pump times *On* (m:s)	*Off* (m:s)
1 Layer					0:32	0:20	0:40	0:29	0:38	0:30	0:39	0:30	0:39	0:30	0:39	0:29	0:39	0:29	0:39	0:29	0:03	2:32	00:29	00:39
2 Layer									0:28	0:18	0:41	0:23	0:39	0:29	0:39	0:29	0:39	0:28	0:39	0:29	0:03	2:32	00:26	00:39
4 Layer	0:28	0:18	0:41	0:23	0:39	0:29	0:39	0:29	0:39	0:28	0:39	0:29	0:38	0:29	0:39	0:29	0:39	0:29	0:39	0:28	0:04	2:31	00:28	00:39

Table 16: Filter clogging results.

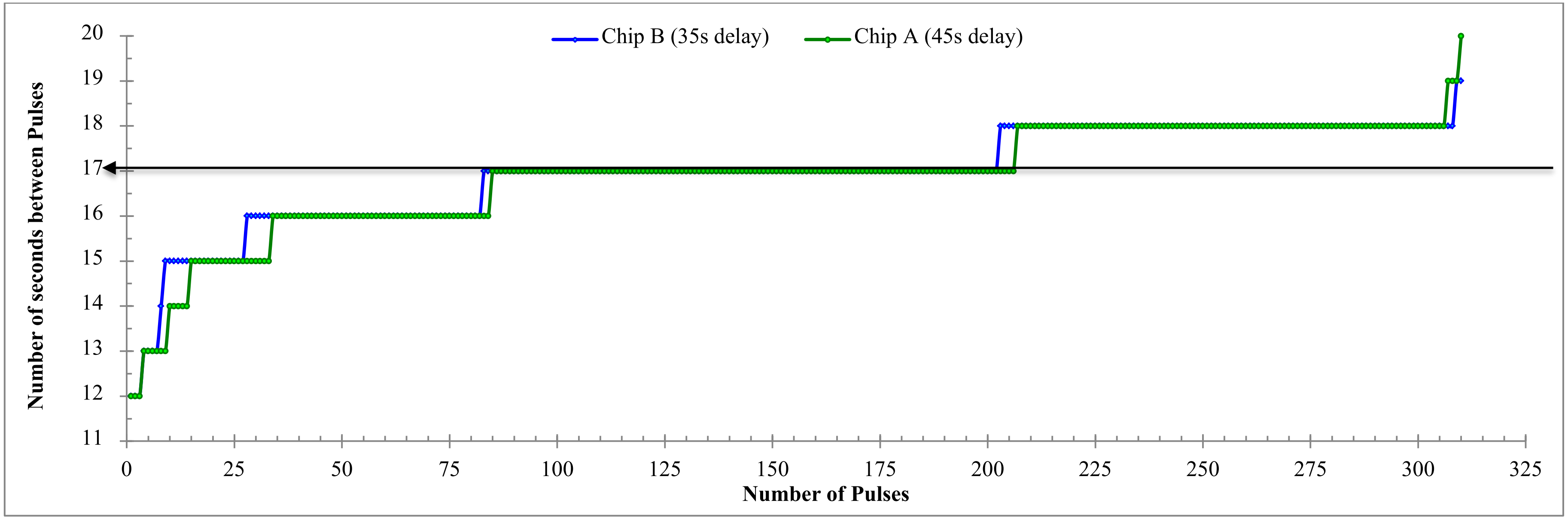


Figure 52: Time duration between pulses.

H3 ENERGY CONSUMPTION PROFILE: FOR CHIP A AND B.

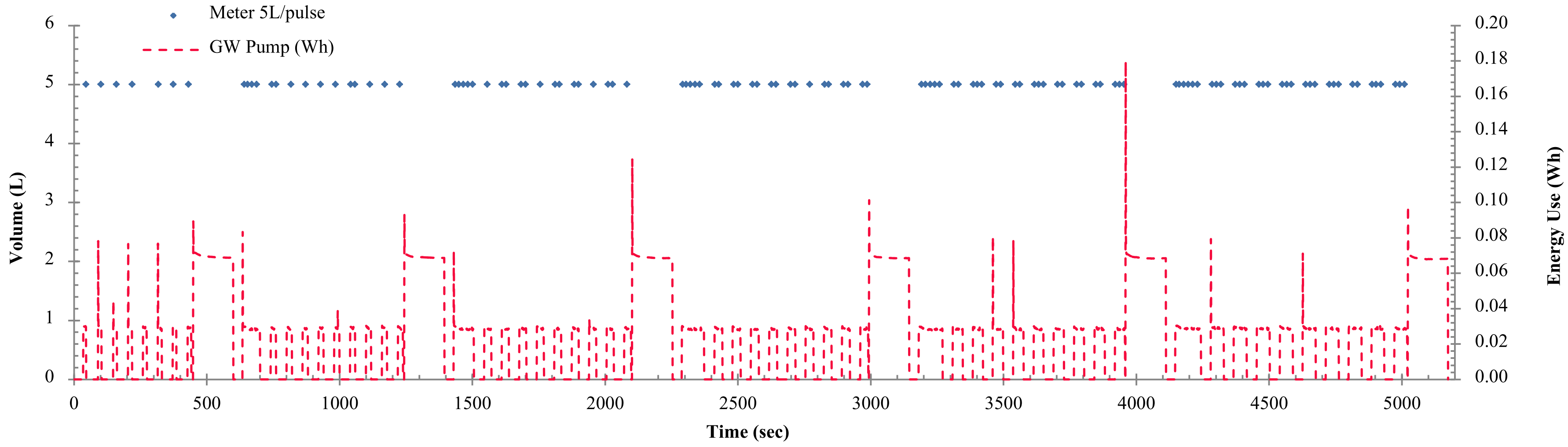


Figure 53: Baselines 6-11 (L/min).[Chip B 35s delay]

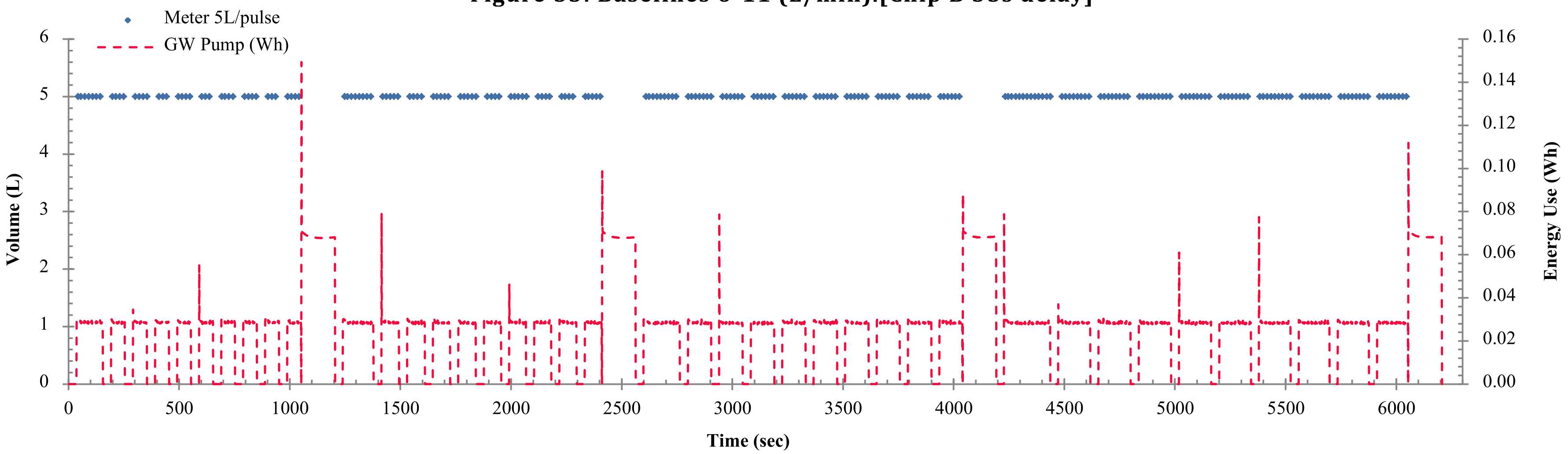


Figure 54: Baseline 12-15 (L/min). [Chip A 35s delay]

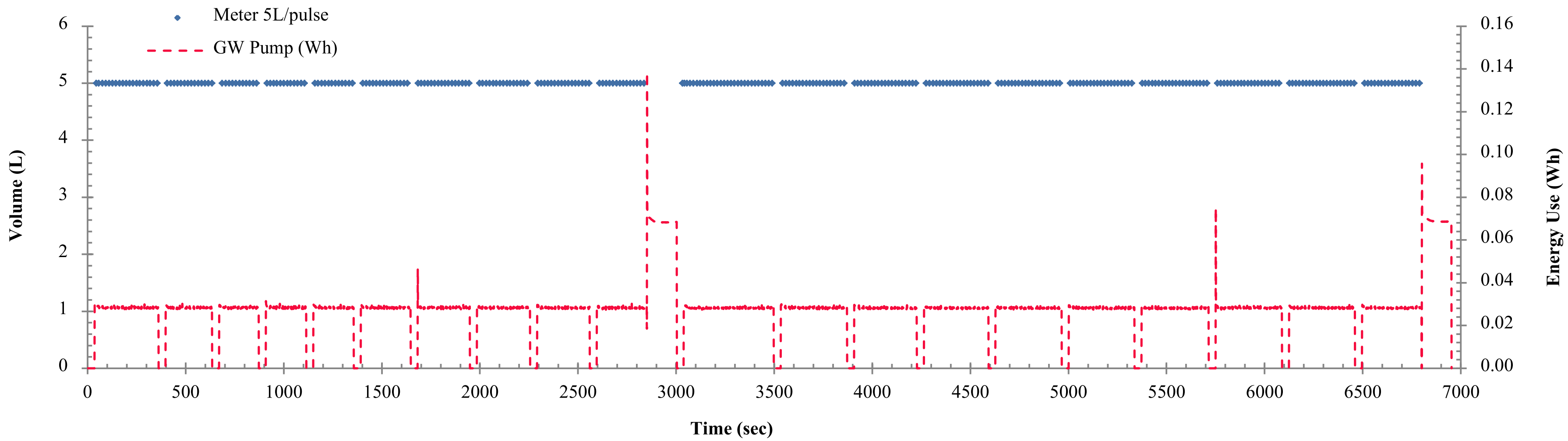


Figure 55: Baseline 16-17 (L/min). [Chip A 35s delay]

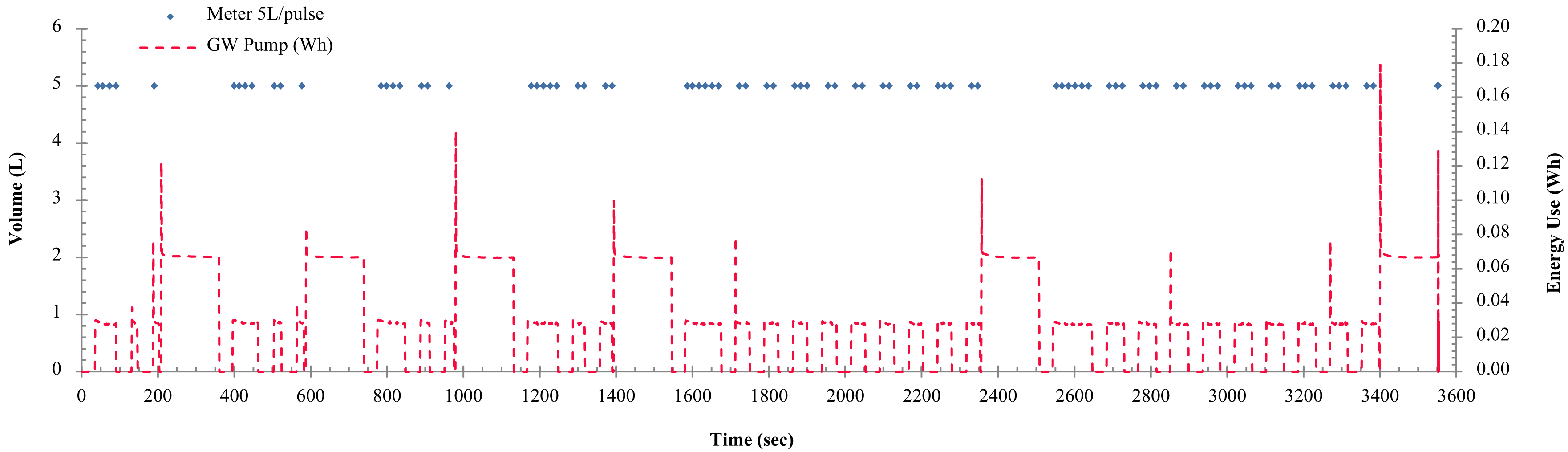


Figure 56: Baseline 6-12 (L/min). [Chip A 45s delay]

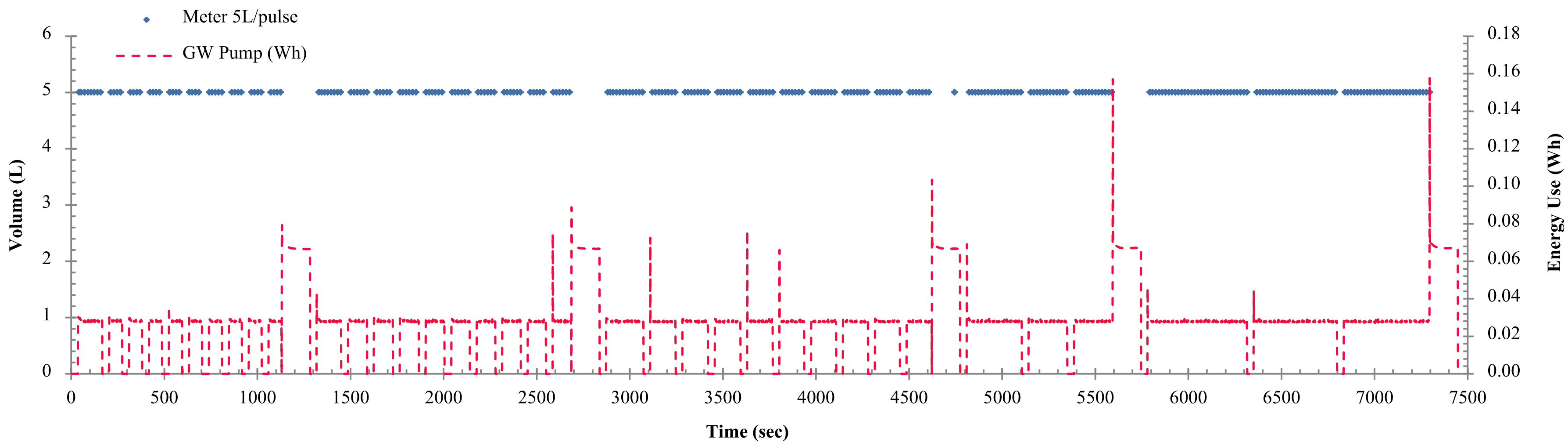


Figure 57: Baseline 13-17 (L/min). [Chip A 45s delay]

Energy Consumption (Wh) with **Chip A** (45s Delay) and **Chip B** (35s Delay)

Energy consumption (Wh) of all chips; A & B		**6 [L/min]**	**7 [L/min]**	**8 [L/min]**	**9 [L/min]**	**10 [L/min]**	**11 [L/min]**	**12 [L/min]**	**13 [L/min]**	**14 [L/min]**	**15 [L/min]**	**16 [L/min]**	**17 [L/min]**
Chip A [Demo]	[3x Cycles]	2.47 2.76	3.06	3.47 3.5	4.07 4.2							19.97	40.29
	Air-blower	10.27 10.32	10.19	10.23 10.27	10.2 10.22							10.34	10.35
Chip A [Domestic]	[10x Cycles]					12.78 12.13	14.51 13.97	16.91	21.46	29.11	39.85 40.49		
	Air-blower					10.18 10.19	10.3 10.16	10.4	10.21	10.16	10.19 10.31		
Chip B [Domestic]	[10x Cycles]	3.33	7.00	8.93	9.90	12.27	15.27	19.17	23.57	31.09	41.81	69.32	95.30
	Air-blower	10.31	10.26	10.35	10.24	10.38	10.15	10.25	10.16	10.17	10.23	10.32	10.27