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An Analysis of the Effectiveness of Mains Water Reduction Strategies in a Medium Density Residential Development in Metropolitan Perth

ENGINEERING HONOURS THESIS (ENG470)

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Abstract
This thesis reviews and quantifies the implementation of mains water reduction strategies in a medium density residential development in a city with a drying climate. *WGV by DevelopmentWA* (WGV) is a 2.2-hectare infill development in the Fremantle suburb White Gum Valley, Perth, Australia. WGV incorporates a number of mains water reduction strategies including water efficiencies, conservation and alternative sources.

This thesis investigates the implementation of these mains water reduction strategies, providing understanding on the impact of the strategies for residents living in the development. Over 60 smart meters were installed at the site to record data on mains, bore and rain water consumption for three dwelling typologies including:

- Detached dwellings: Assumed occupancy of 2.8 people per dwelling with an average of 105m^2 per person with no common walls between dwellings.
- Attached dwellings: Assumed occupancy of 2.8 people per dwelling with an average area of 45m^2 per person with common walls between dwellings.
- Multi-residential (Apartment) dwellings: Assumed occupancy of 1.8 people per dwelling with an average area of 55m^2 per person.

The results demonstrated that residents living in *WGV* reduce their total water consumption by 48% whilst reducing their mains water consumption by approximately 64% in comparison to the typical Perth home. This is an 8% difference to the preliminary modelling completed by *Josh Byrne & Associates (*JBA) which predicted a mains water savings of 72%.

Attached dwelling residents were the lowest mains water consumers, using 20kL/person of mains water per year (81% reduction on Perth average) whilst Apartment residents consume 32kL per year (70% reduction) and Detached residents consume 52kL per year (51% reduction).

The thesis also found that the community bore system had been implemented successfully. Direct on-site infiltration was determined to be greater than the groundwater abstraction rate, leading to the conclusion that the community bore at WGV is sustainably managed.

Future policy implications following this study should include industry and governmental agencies investigating the implementation of small-scale decentralised alternative water sources and the water efficiencies and conservation strategies presented in this thesis.

A number of further studies are recommended including a detailed analysis of the Design Guidelines provided to residents by DevelopmentWA to further understand the large variation in water consumption levels of resident living within the WGV precinct. This study would include household audits and surveys with residents to provide a breakdown of the effectiveness of each water reduction initiative implemented to better understand the influence of the Design Guidelines.

Overall, *WGV* has been successful at reducing its mains water consumption by 64% which is within 10% of the predicted savings in the preliminary modelling completed by JBA.

Table of Contents

List of Tables

List of Figures

1 Introduction

This Honours project investigates the effectiveness of the mains water reduction strategies for a medium density residential development in Metropolitan Perth. *WGV by DevelopmentWA* (WGV) is analysed as a case study to identify its water consumption data and positive groundwater recharge data as a result of the water reduction strategies applied within the precinct. In particular, the mains water consumption data collected is compared to the typical water consumption for households within the Perth Metropolitan area and compared to the WGV project modelling estimates provided by *Josh Byrne & Associates* (JBA) (Byrne et al. 2018). The project involved conducting site visits to WGV for the installation of data loggers on to all water meters located within the precinct, as well as to take manual meter readings in order to verify remotely gathered data. The project identifies the effect of providing Design Guidelines (DGs) to residents in the development phase of a precinct as a mechanism of implementing mains water reduction strategies and the impact it has on each household's water consumption.

1.1 WGV by DevelopmentWA

WGV is a 2.2ha infill development in the Fremantle suburb of White Gum Valley, Western Australia (LandCorp 2016). WGV will eventually comprise around 80 residential dwellings and once completed it will accommodate approximately 180 residents in a range of typologies including (Byrne et al. 2018):

- Detached dwellings: There are 22 detached (no common walls) residential dwellings ranging in size from 250m^2 – 350 m^2 within the WGV development. To date, all detached lot owners have agreed to install a 3kL rainwater tank as part of a DevelopmentWA sustainability package that covers the cost of the system. All meters installed at the detached lots are Itron water meters.
- Attached dwellings: There is a one duplex site at WGV. The two attached dwellings share a rainwater system, and their mains water supply is connected at a single meter. They are connected to the shared bore for irrigation supply, again at a single point of supply for the site.
- Multi-residential (Apartments) dwellings: There are currently three apartment complexes at WGV. These include:
    - SHAC (Sustainable Housing for Artists and Creatives) apartments which contains 12 dwellings that are currently fully occupied, plus two studios, which have water consumption being monitored.
    - Evermore apartments (24 dwellings) which is now almost fully occupied.
    - GenY Demonstration House which consists of three apartments that are all occupied.

  A fourth apartment building, plus a group housing development are also planned for WGV – these will be part of the WDE project once built and occupied.
  All occupied apartments are being monitored with the water consumption data being captured. Mains water is connected to the apartment lots through Elster water meters, each with a probe sensor connected for remote reading. Itron meters are in use for the community bore connections.

  SHAC and Evermore apartments do not have access to any rainwater for internal uses. GenY has a shared 1okL rainwater tank underground in the central courtyard of the complex which supplies water for washing machines and toilet flushing, with each apartment's consumption of the rainwater supply individually metered.

WGV integrates a unique set of leading-edge water reduction strategies with climate sensitive considerations, and creative urban greening to be the first certified 'One Planet Community' in Western Australia (Bioregional 2017). The WGV Waterwise Development Exemplar (WGV WDE) is a collaboration between DevelopmentWA, Water Corporation and other parties to monitor, analyse and communicate the water management outcomes at WGV. The WGV WDE is testing the objective of reducing mains water consumption by 60 – 70% compared to the Perth average mains water consumption through various water reduction strategies. The key water reduction strategies include efficiency measures, rainwater harvesting, and community bore irrigation supply for both residential and public open space (Byrne et al. 2018).

A range of existing research programs are underway at WGV including partnerships between the Water Corporation, Cooperative Research Centre (CRC) for Water Sensitive Cities, the City of Fremantle, JBA, and DevelopmentWA (formerly known as LandCorp). These organisations are currently examining the performance of dwellings including water and energy as well as broader environmental performance such as the groundwater recharge model (CRCWSC 2017). JBA were the landscape architects and urban water consultants for WGV and now lead an applied research program to capture and share the learnings from the water related initiatives at the site.

Figure 1. WGV subdivision plan showing lot layout, roads, laneways, and verges. Source: JBA

1.2 Research Question

The research question this thesis will address is:

Has the implementation of Mains Water Reduction Strategies at WGV been effective in reducing mains water consumption of residents in the precinct? Specifically:

a. *Can lot-scale rainwater harvesting be used effectively to reduce resident's reliance on mains water year around?*
b. *What role do residential community bores play in reducing mains water consumption when used for private lot irrigation? Can this be done sustainably?*

1.3 Aim & Objectives

The overall aim of the study is to collect water consumption data from WGV to evaluate the performance of the water reduction strategies deployed within the precinct. The main objectives for this project include:

1. Understanding the impact of the water reduction strategies at WGV in relations to mains water savings.
2. Understanding the reasons for variations from the designed modelling.
3. Ascertain the sustainability of groundwater abstraction at WGV with reference to the original design model.

1.4 Thesis Structure and Scope

Section 1 (Introduction) provides a general background and context to the study, whilst identifying the aims of the thesis and establishing the key research question that are addressed. The case study for this thesis, *WGV,* is introduced providing a general background of the precinct and the various research projects that have previously been completed at the site.

Section 2 (Literature Review) provides a detailed review of the literature that is broken down into five separate sections. Section 2.1 reviews Perth's climate providing evidence of an increase in extreme weather events including a reduction in rainfall over the last two decades, a direct result of climate change. Section 2.2 discusses Perth's constrained water supply that incorporates a majority of energy intensive large-scale desalination and recent water consumption restrictions enforced by the State Government. Section 2.3 reviews Urban Water Management concepts including Water Sensitive Urban Design (WSUD) and Integrated Urban Water management (IUWM). Section 2.4 discusses the implication of rapid urbanisation causing the need for current water infrastructure to be addressed for liveability. Section 2.5 provides a detailed review of existing case studies from around the world that have implemented Mains Water Reduction strategies and whether those strategies have been successful or not.

Section 3 (Methodology) introduces the methodology used for this thesis, as an original contribution to the literature as recognised in Section 2. This section identifies how the data was collected for the study including the installation and commissioning of smart meters at *WGV* with a number of schematic diagrams used to demonstrate the configuration. A detailed examination of the smart meter specifications is also provided in this section.

Section 4 (Results and Discussion) presents the results of the detailed analysis undertaken for this thesis and provides the evaluation and synthesis of the results. The results include data from Mains, Bore and Rain Water consumption from residents living within *WGV*. Comparisons are drawn on between the preliminary modelled figures completed by JBA as illustrated in section 3 and the occupancy data collected for this thesis. The precinct water consumption data is presented for further understanding of the water balance completed by JBA in the design phase and whether the current precinct consumption is providing sustainable abstraction from the community bore.

Section 6 (Conclusion) concludes the thesis by summarising how the aims of the study have been addressed, and further work that can be completed to progress the implementation of mains water reduction strategies.

The Appendices provide supporting material that is referred to in the body of the thesis. It provides relevant insight into the data analysis process.

2 Literature Review

This literature review sets out to provide context for understanding the importance of mains water reduction strategies in residential developments. Section 2.1 describes the current climate in Perth, Western Australia, prior to Section 2.2 that examines Perth's constrained water supply due to the impacts of climate change and urbanisation. Section 2.3 discusses urban water management and introduces both Water Sensitive Urban Design (WSUD) and Integrated Urban Water Management (IUWM). Liveability in urban metropolitan areas is then discussed in Section 2.4. Section 2.5 identifies key Water Reduction Strategies that have been researched extensively in the literature, before introducing two best practice case studies; Lochiel Park in Adelaide and Aurora Estate in Melbourne. Section 2.6 introduces the case study for this thesis, WGV.

2.1 Perth's Drying Climate

Perth's changing climate has resulted in a significant reduction in annual rainfall and an increase in extreme weather events (Bureau of Meteorology (BoM) and CSIRO 2016). Historical data shows that over the last 30 years, annual rainfall has declined by 15% (Bureau of Meterology 2018), which is representative of mid-latitude western coast lines. Perth has an increasing population (Australian Bureau of Statistics (ABS) 2011), leading to the prediction of mains water demand doubling over the next 40 years (Department of Water 2014), demonstrating the city's rapid urbanisation.

Perth has a drying Mediterranean climate that is located on the Swan Coastal Plain, it has a relatively unique geology as it sits on top of an onshore and an offshore sedimentary basin that stretches 1300 km from north to south (Department of Water 2014). Perth consists of two main groundwater systems; the Gnangara and the Jandakot groundwater system (Diaper et al. 2007). The Gnangara system has seen an increase in abstraction that accounts for the depletion in water levels by approximately 23% (Elmahdi and McFarlane 2009). The Gnangara system's water levels have been impacted by both climate change and urbanisation (Xu 2008). In 2012, approximately 60% of Perth's public water supply was sourced from the Gnangara Groundwater System (Skurray 2015). The superficial aquifer is also facing the impact from urbanisation from excess abstraction, which is understood to be a consequence of a combination between pine plantations and unregulated bores across Perth (Shukla 2016). Over the last four decades, annual abstraction has increased by around 350%, leading to the over-allocation by approximately 70% of groundwater sources (Salama 2005). Borehole data suggests that Perth is facing its warmest temperature on record for at least 500 years (Appleyard 2005), with over 80% more droughts expected to occur in the region by 2070 (Department of Climate Change 2009). As annual rainfall continues to decline at a predicted rate of 15% by 2030, it is estimated that a reduction in the aquifer recharge rate will also decline by up to 49% (Ali et al. 2012).

2.2 Perth's Constrained Water Supply

Perth's Integrated Water Supply Scheme (IWSS) consists of 48% seawater desalination, 40% groundwater extraction, 10% surface water and 2% groundwater replenishment, which is a significant change to Perth's previous dependence on surface water for potable use (Water Corporation 2017). The Water Corporation expect that the Groundwater Replenishment scheme will supply 20% or 115 GL per annum of Perth's water by 2060 (Water Corporation 2017). The increase dependence in large-scale seawater desalination has led to the increase cost of mains water due to the desalination process being highly energy intensive (Diaper et al. 2007). The average per capita energy consumption for water supply services in Perth, is approximately 247 kWh per person per year, which is almost five times larger than South East Queensland (53 kWh per person per year), a State that is not dependent on seawater reverse osmosis desalination (Lam et al. 2016). Simms et al (2017) claims that a typical RO desalination production of potable water requires 3.6 – 5 kWh/m3 in comparison to groundwater extraction and surface water pumping which requires 0.13 – 0.6 kWh/m3 and 0.04 – 0.3 kWh/m3 (Simms et al. 2017), demonstrating the current energy intensity of Perth's main source of potable water, as seen in Figure 1.

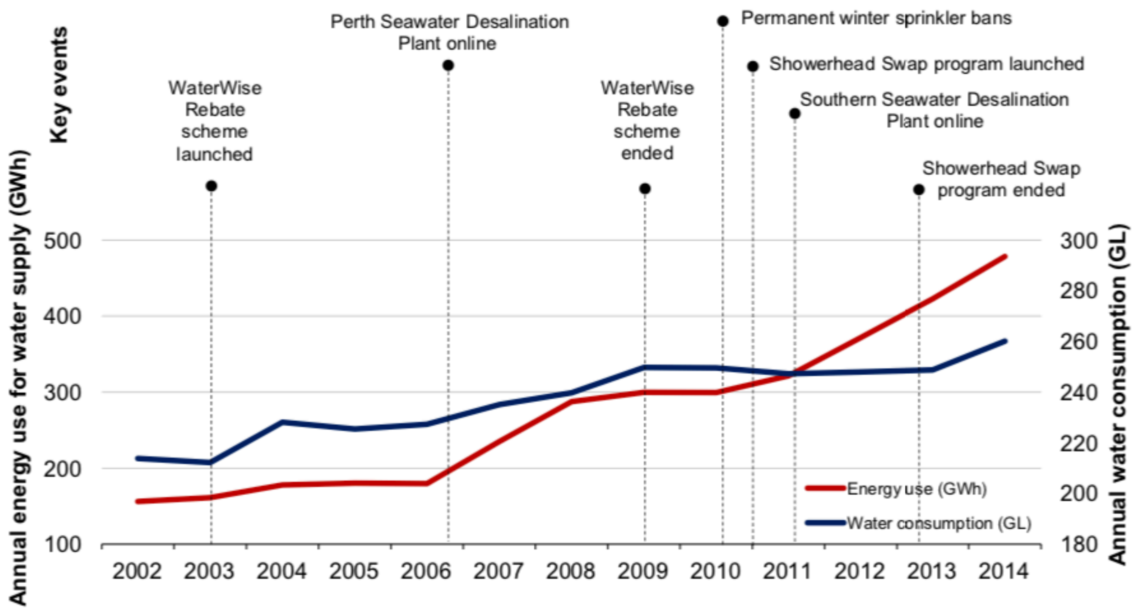

Figure 2. Water and Energy Consumption for Perth's Urban Water Supply (Lam et al. 2016).

Water usage restrictions by the State Government have been put in place, after three major historical events that caused significant mains water reductions. These restrictions include (Water Corporation 2010):

- Pay for use and total sprinkler ban, 1977;
- Daytime sprinkler bans and Waterwise messaging, 1995;
- Two day a week watering roster, 2002.

Despite these restrictions, Western Australia continues to be the largest household water consumer in Australia, in which 78% of the population is located in Metropolitan Perth. It is estimated that residents consume an average of 298 litres per person per day in comparison to the Australian average of 219 litres per person per day (Water Corporation 2010; ABS 2014). In response to this, there has been a further local emphasis on reducing mains water consumption which is constrained under the current system network design. More recent mains water reduction strategies in Perth have been implemented with limited progress made, these include (Water Corporation 2010):

- Waterwise Rebate Scheme Launched, 2003.
- Permanent winter sprinkler bans, 2010.
- Showerhead swap program launched, 2011.

The common household in the Perth metropolitan area has one source of water in the reticulation systems, potable mains (scheme) water (Bettini et al. 2015). However, Perth residents only consume approximately 50% for potable purposes (Water Corporation 2010), with over 40% of total water consumption used for domestic irrigation (Water Corporation 2010).

2.3 Urban Water Management

Urbanisation has caused major problems for the natural process of stormwater runoff, including the increased peak and volume of runoff, as well as reduced infiltration, and low water quality (Pazwash 2011). Hudson recognised that urbanisation replaces natural vegetation that provided permeability with impervious surfaces such as roads and roofs, leading to a reduction of infiltration that would have recharged local aquifers (Hudson 1994). Whilst Coutts et al argues that different water streams have conventionally been managed separately with little thought about connecting water, wastewater and stormwater services to close the loop on water and nutrient cycles (Coutts et al. 2013). This approach has led to a wasted resource, resulting in water shortages, concerns about water quality and unsustainable practices. Saptoka et al claims that for water to be managed efficiently, the current approach must change to a more holistic integration of centralised and decentralised solutions that are embedded into the urban form (Sapkota et al. 2013).

Water Sensitive Urban Design (WSUD) focuses on approaches that integrate the water cycle with the local context and urban environment (Coutts et al. 2013), it reduces the impact of stormwater runoff events through the implementation of infiltration basins in the urban form that can also aid aquifer recharge and local surrounding water bodies (Dillion 2005). Schirmer states that the benefits of WSUD approaches include increased water quality, flood risk mitigation, alternative water supplies, liveability, biodiversity improvement, reclaimed natural habitats, ecosystems for wildlife, etc (Schirmer and Dyer 2018). Progressively, WSUD aims to retain water for long periods prior to reuse in the urban water cycle through natural processes such as infiltration, evaporation, and evapotranspiration (Broadbent et al. 2018). WSUD approaches in Australia have seen the development of smaller lot sizes that are better integrated with local infrastructure, public open space, ongoing management and monitoring, and water-sensitive design principles (Hedgecock and Moritz 1993). Another approach that has been developed to deal with modern day water cycles is Integrated Urban Water Management (IUWM), which provides a set of principles to support improved organised, reactive, and sustainable resources management practice (Cameron 2017). Both WSUD and IUWM aim to harvest stormwater and reduce flooding, a figure demonstrating the difference between the two can be seen in Figure 2.

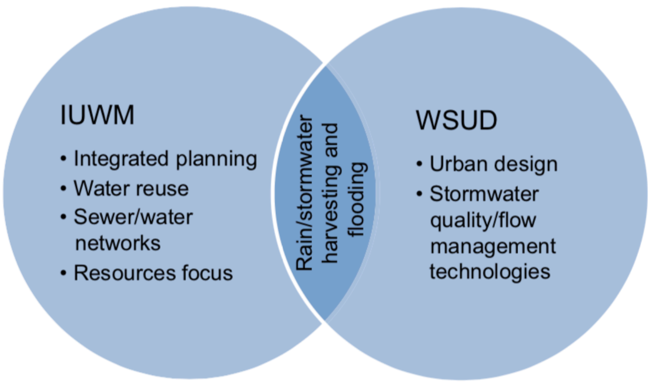

Figure 3. Relationship between IUWM and WSUD typically used in practice (Furlong et al. 2018).

2.4 WSUD in Denser Urbanisation and for Liveability

Kerkez et al recognise that rapid urbanisation has led to challenges for current water infrastructure to retain and treat water sources onsite (Kerkez et al. 2016). Grose estimates suggest that the Perth Metropolitan area will continue to densify over the coming years with many suburbs expected to double their dwelling numbers by 2050 and infill development projected to represent 47% of all new dwellings in the same period (Grose 2009). Conventional stormwater management must transform to sustainable stormwater management that is integrated into the streetscape and landscape design to assure proper treatment of runoff (Barbosa et al. 2012). In urban areas following rainfall, stormwater begins to move from one point to another, this is defined as runoff, which if not handled correctly can cause environmental damage on surrounding water bodies. Through the implementation of green infrastructure in the context of WSUD approaches, natural vegetation and urban greening can be utilised as a means of improving local infiltration to minimise stormwater runoff (Walsh et al. 2012). Integrated urban planning concepts highlight opportunities that arise in designing liveable urban environments.

Leonard et al conducted a study that compared six WSUD case studies in Adelaide, all projects included urban greening in public open space that provided infiltration and retention of stormwater onsite (Leonard et al. 2012). Following the study, Leonard et al (2018) initiated residential surveys and one of the main findings was that participants felt there were major recreational and health benefits from the implementation of urban greening, with many stating they were more likely to partake in exercise such as walking, jogging or cycling around there precincts (Leonard et al. 2018). Even when small WSUD techniques had been implemented, there were a number of benefits including the reduction of urban heating which again encouraged residents to participate in recreational activities (AECOM 2017).

2.5 Mains Water Reduction Strategies

There are a number of mains water reduction and management initiatives that recur in the literature. This section covers these in general, including international case studies that include the reported impacts of the alternative water source initiatives.

Water Efficient Appliances

Water efficient appliances aim to utilise appliances that use water more conservatively in comparison to conventional technology whilst maintaining the comfort of residents (Dieu-Hang et al. 2017). According to Marinoski et al water efficient appliances includes dishwashers and washing machines (Marinoski et al. 2018), in which a number of studies have analysed trends in water reduction consumption for households utilising these technologies (Pérez-Urdiales and Garcia-Valinas 2016, Dieu-Hang et al. 2017). Carragher et al. (2012) monitored residential households that were retrofitted with water efficiency appliances, the results demonstrated that a reduction of 16% in average day peak hour water consumption was achieved in comparison to typical consumers (Carragher et al. 2012). In Australia, Nationally recognised guidance material includes the Water Efficiency Labelling and Standards (WELS) scheme and the Smart Approved Water Mark (SAWM) scheme (Joint Steering Committee for Water Sensitive Cities (JSCWSC) 2009).

Water Efficient Fittings

Water efficient fitting are much like water efficient appliances as they aim to reduce flowrates to conserve water (Dieu-Hang et al. 2017). Technology includes low volume or dual flush toilets; water flow restrictor for taps; low flow shower heads; etc (Tam and Brohier 2013). Literature suggests that the implementation of Water Efficient Fittings can reduce indoor and outdoor water consumption by approximately 11 – 15% (Joint Steering Committee for Water Sensitive Cities (JSCWSC) 2009).

Outdoor Water Efficiency

Outdoor water efficiency refers to water savings through the implementation of efficient outdoor practices that reduce water consumption (Landon et al. 2017). Many studies around the world recognise residential irrigation as a major water consumer (Byrne 2016), with the potential of implementing efficiencies to significantly reduce irrigation demands (Patterson 2004). According to Reyes-Paecke et al a number of outdoor water efficient strategies exist including (Reyes-Paecke et al. 2019):

- Utilising native plants and drought tolerant plants.
- Mulching provides reduction in evaporation providing water to infiltrate and more efficient evapotranspiration.
- Subsurface dripline irrigation.
- Effective Hydrozoning for effective irrigation management.

Smart Metering

Boyle et al states the importance of Smart Metering in the water urban environment which is further complemented through the advancement in cost effective, non-mechanical water meters (Boyle et al. 2013). Gurung and Sharma findings suggest that monitoring residential water consumption provides the opportunity to detect any unexpected water consumption patterns leading to the identification of leaks and a reduction in annual water consumption (Gurung et al. 2015). Anda et al conducted a study in the City of Fremantle, Perth, Western Australia, which implemented smart metering to 36 participating households with the aim of integrating smart metering with hybrid water systems. The current data collection demonstrates a saving of 20% in mains water through both leakage detection and change in water consumption due to residential monitoring and analysis (Anda et al. 2019).

Behavioural Change

Anda and Temmen claim that through educating residents on their water consumption significant changes in behaviour are possible to successfully reduce water consumption (Anda and Temmen 2014). Byrne et al demonstrates that developers have the opportunity to provide residents with information packs and fact sheets about water conservation when moving into new developments (Byrne et al. 2018). A behavioural change pilot project was designed and implemented to over 1,000 residents in the South-West of Western Australia. The yearlong study found that an average saving of 12% was achieved through the program which included raising awareness for water conservation, as well as delivering information on methods for water reductions (Anda et al. 2013). A number of other studies demonstrate similar water reduction savings (Sheehy 2005, Anda et al. 2012).

Rainwater Harvesting

Rainwater harvesting has been utilised as a source of water since the beginning of urbanisation (Furumai 2008). In recent times the implementation of rainwater harvesting has dramatically reduced as a major water source (Abdulla and Al-Shareef 2009), this has been recognised as a direct result of declining rainfall patterns due to climate change in a number of cities around the world (Musayev et al. 2018, Haque et al. 2016, Zhang et al. 2019). Gleason Espíndola et al suggests that rainwater harvesting should be integrated into residential water profiles to reduce the reliance on centralised large-scale systems that are energy-intensive (Gleason Espíndola et al. 2018). Zhang et al claims that as the impacts of climate change continue to be faced a diverse range of water sources should be integrated into the residential water profile (Zhang et al. 2019).

A number of studies have identified the potential of rainwater harvesting as an alternative water supply through detailed modelling for both lot and cluster scale storage settings

(Rashidi Mehrabadi et al. 2013, Steffen et al. 2013). Rainwater is generally used as a water source for toilet and washing machine use as limited treatment is required (White 2009) however projects have begun to use it as a source of hot water within residential developments (Chao et al. 2015). Rainwater harvesting benefits double as they can also be used as an approach to WSUD through capturing stormwater that may have otherwise been runoff which can lead to potential environmental harm (Gurung et al. 2014). Coombes demonstrated that a communal rainwater harvesting scheme can significantly reduce scheme water reliance by meeting up to 60% of residential water demand (Coombes and Kuczera 2003). Rainwater case studies have been tabulated in Table 1.

Table 1. Rainwater Harvesting Case Studies

PROJECTS	AQUAREVO[1]	CURRUMBIN ECOVILLAGE [2]	LOCHIEL PARK[3]	CHICAGO[4]	WGV*
LOCATION	Victoria, Australia	Queensland	South Australia	United States of America	Western Australia
CLIMATE	Sub-Mediterranean	Tropical	Mediterranean	Temperate	Mediterranean
AVERAGE ANNUAL RAINFALL	603mm (Bureau of Meterology 2019)	1521mm (Bureau of Meterology 2019)	384mm (Bureau of Meterology 2019)	855mm (Rostad 2016)	706mm (Bureau of Meterology 2019)
SIZE OF DEVELOPMENT	46 ha	110ha	15ha	NA	2.2ha
DWELLINGS	460	144	106	NA	82
MANDATED TANK SIZING	2.4kL per dwelling	20 – 40 kL depending on number of bedrooms (1 bedroom = 20kL, 3 bedrooms + = 40kL).	1.5kL per dwelling	5kL	3kL per detached dwelling
MINIMUM ROOF CATCHMENT	$100m^2$	Whole roof	80%	$100m^2$	$70m^2$
APPLICATION	Hot water Supply	All potable sources	Non-potable hot water taps and showers	Toilets	Toilets and Washing Machine
STATE AVERAGE WATER CONSUMPTION	54 kL/person/year (Gan and Redhead 2013)	56 kL/person/year (Beal et al. 2010)	105 kL/person/year (Office for Water Security 2010)	88 kL/person/year	106 kL/person/year (Water Corporation 2010)
MODELLED SAVING	19 kL/person/year	36.5 kL/person/year	33 kL/person/year	13 kL/person/year	10 kL/person/year
MODELLED SAVING [%]	35%	65%	31%	15%	9%
MEASURED SAVING	NA	NA	NA	NA	TBC
MEASURED SAVING [%]	NA	NA	NA	NA	TBC
COMMENT	First major application of rainwater	First Australian urban residential development that	Recognised as South Australia's first Carbon	Case Study for Rainwater	Find further information in Section 1.6.

PROJECTS	AQUAREVO[1]	CURRUMBIN ECOVILLAGE [2]	LOCHIEL PARK[3]	CHICAGO[4]	WGV*
	harvesting for hot water use in Victoria, Australia.	is 'off-the-grid' for water.	Neutral housing options.	tanks in the City of Chicago	

[1] (CRCWSC 2017); [2] (CRCWSC 2018); [3] (Sharma et al. 2016); [4] (Rostad et al. 2016); * (CRCWSC 2017)

Stormwater Harvesting

McArdle et al found that collecting stormwater for reuse as a residential water source has the potential to significantly reduce mains water consumption in residential developments (McArdle et al. 2011). According to literature this provides multiple benefits as it can enable aquifer recharge, reduce stormwater runoff, and retain water onsite (Leonard et al. 2015). Page et al recognised that the major problem for stormwater reuse is the storage of the source for use in dry weather conditions (Page et al. 2010), however McArdle et al developed the concept of using urban lakes, wetlands and aquifers as the main storage function that also enables urban greening in residential precincts (McArdle et al. 2011). Building on this Burns et al found that the integration of individual or cluster scale rainwater tanks also provide sufficient storage which has been identified as green infrastructure (Burns et al. 2015). A number of case studies have been implemented; the best practice scenarios can be seen in Table 2.

Table 2. Stormwater Harvesting Case Studies

TIME	ORANGE[7]	LOCHIEL PARK[3]	WARRNABOOL[8]	SPONGE CITY [9]
LOCATION	New South Wales	South Australia	Victoria	Wuhan, China
CLIMATE	Sub-Mediterranean	Mediterranean	Sub-Mediterranean	Subtropical
ANNUAL RAINFALL	916mm (Bureau of Meterology 2019)	384mm (Bureau of Meterology 2019)	603mm (Bureau of Meterology 2019)	1100mm
SIZE	287km2	15ha	NA	NA
ACCOMMODATING	40,300 residents	106 dwellings	NA	NA
REDUCTION STRATEGY	Utilise a $34km^2$ catchment that collects 70% of the city's stormwater	Captures stormwater from a 190ha urban catchment, the stormwater is then treated through a constructed wetland	This stormwater harvesting scheme captures stormwater from all new houses and industrial buildings within new estates to meet the regions water demand	Building natural hydrological cycle protection and resilience for stormwater reuse to supply non-potable sources
APPLICATION	Potable	Toilets, washing machine and irrigation	Potable	Non-potable sources
REGIONS AVERAGE WATER CONSUMPTION	118 kL/person/year	105 kL/person/year (Office for	54 kL/person/year (Gan and Redhead 2013)	103 kL/person/year (IBNET 2004)

TIME	ORANGE[7]	LOCHIEL PARK[3]	WARRNABOOL[8]	SPONGE CITY [9]
	(Sydney Water 2018)	Water Security 2010)		
MODELLED SAVING	1,350 ML/year	42 kL/person/year	145 kL/dwelling/year	72 kL/person/year
MODELLED SAVING [%]	25%	40%	100%	70%
ACTUAL SAVING	850 ML/year	0 kL/person/year	109 kL/dwelling/year	NA
ACTUAL SAVING [%]	16%	0%	75% currently	NA
COMMENT	A large-scale scheme that captures stormwater for reuse as a potable water sources in a town that is prone to droughts	Recognised as South Australia's first Carbon Neutral housing options	By 2055 the project is expected to meet 100% of the water demand	The Chinese Government aim for 20% of urban area to utilise sponge city concept by 2020 and 80% by 2030

[7] (CRCWSC 2018); [3] (Sharma et al. 2016); [8] (CRCWSC 2018) ; [9] (Cook et al. 2018)

Groundwater

Groundwater has an important role in sustaining urban environments, Hansen findings suggest that the use of groundwater should only be used if the correct modelling has been completed allowing for net zero abstraction (Hansen 2012). Groundwater sources have conventionally been implemented on both lot-scale and large-scale water networks (Nel et al. 2017). In Perth, Australia, it is estimated that there are over 180,000 residential bores that draw from shallow aquifers (Department of Water 2014), whilst the Integrated Water Supply Scheme consists of 46% groundwater abstraction (Water Corporation 2017). Bricker et al suggests that groundwater can be utilised as a local alternative irrigation source for residents to reduce mains water consumption in residential developments through the implementation of community scale bores (Bricker et al. 2017). Hilten et al developed and demonstrated a stormwater model that provides a net zero abstraction rate whilst successfully recharging the local aquifer (Hilten et al. 2008). Whilst JBA have formulated a water balance at WGV that enables stormwater to recharge the local aquifer whilst utilising a community bore that provides a sufficient amount of water for both residential and POS irrigation in a medium density residential development (New WAter Ways 2018). A number of groundwater projects have been implemented around the world, a sample of these can be seen in Table 3.

Table 3. Groundwater Case Studies

PROJECTS	ROSEHILL WATERS[5]	CAPO DI MONTE (CDM)[6]	MONTEBELLO FOREBAY[12]	WGV*
LOCATION	Western Australia	Queensland	California, USA	Western Australia
CLIMATE	Mediterranean	Tropical	Semi-arid	Mediterranean
SIZE	47ha	NA	NA	2.2ha
ACCOMMODATING	800 dwellings	46 dwellings	NA	82 dwellings, 179 residents
REDUCTION STRATEGY	Connected to a community bore for POS and residential irrigation requirements	Integrate rainwater harvesting with groundwater for a communal scale bore	A Managed Aquifer Recharge Scheme that abstracts much less then it recharges in the drought prone American State	A community bore that provides all residential and POS irrigation.
APPLICATION	Irrigation	Toilets and irrigation	Potable	Irrigation
REGION AVERAGE WATER CONSUMPTION	106 kL/person/year (Water Corporation 2010)	56 kL/person/year (Beal et al. 2010)	117 kL/person/year (Legislative Analyst's Office 2017)	106 kL/person/year (Water Corporation 2010)
MODELLED SAVING [KL/PERSON/YEAR]	42 kL/person/year	32 kL/person/year	30 kL/person/year	42 kL/person/year
MODELLED SAVING [%]	40%	57%	26%	40%
ACTUAL SAVING [KL/PERSON/YEAR]	NA	38 kL/person/year	47 kL/person/year	TBC
ACTUAL SAVING [%]	NA	68%	40%	TBC

[5] (Handle Property Group 2015); [6] (Cook et al. 2013); [12] (Gasca and Hartling 2012); * (CRCWSC 2017)

Wastewater Reuse

Over a decade ago Gikas and Tchobanoglous claimed that wastewater could be treated to any required quality necessary for reuse through decentralised wastewater management systems (Gikas and Tchobanoglous 2009). Since then a number of projects have utilised wastewater as a resource to enable reuse to supply various applications (Priest et al. 2004, Evans et al. 2008, Evans et al. 2009, Friedler and Hadari 2006, Ghisi and De Oliveria 2007). Household wastewater contains two different streams, greywater and blackwater (Schmack et al. 2019). According to Nolde greywater consists of shower, baths and laundry water that can be treated and then typically used for sub-surface drip irrigation (Molde 2000). Whilst Ghishi states blackwater is more contaminated then grey water and comprises of toilet waste which can then be treated and reused (Ghisi and De Oliveria 2007). Hernandez Leal et al findings suggest that 75% of wastewater is in the form of greywater whilst approximately 90% of wastewater is classed as a combination of both greywater and blackwater (Hernandez Leal et al. 2010). A number of wastewater reuse schemes have been developed global, with public perception being the main concern for mass uptake (Dolnicar and Schafer 2006, Finley et al.

2009, Hurliman and Dolnicar 2013, Hurliman and McKay 2007, Marks 2004), some best practice case studies can be seen in Table 4.

Table 4. Wastewater Reuse Case Studies

PROJECTS	AQUAREVO[1]	AURORA ESTATE[10]	CURRUMBIN ECOVILLAGE[2]	SOUTHERN ONTARIO[11]
LOCATION	Victoria	Victoria	Queensland	Canada
CLIMATE	Sub-Mediterranean	Sub-Mediterranean	Tropical	Continental
SIZE	46ha	700ha	110ha	NA
NUMBER OF DWELLINGS	460	7500	144	22
REDUCTION STRATEGY	Wastewater from dwellings is treated on-site prior to be recycled to homes as a non-potable water source	A third pipe system that supplies water from a centralised wastewater treatment plant for residential use	All wastewater is collected by a low infiltration sewer reticulation system and treated for on-site recycling	Small-scale grey water treatment unit for individual dwellings. Collects and treats shower water
APPLICATION	Irrigation and Coldwater for washing machine and toilet water	Toilet, laundry, residential and POS irrigation	Irrigation	Toilet
REGION AVERAGE WATER CONSUMPTION	54 kL/person/year (Gan and Redhead 2013)	54 kL/person/year (Gan and Redhead 2013)	56 kL/person/year (Beal et al. 2010)	100 kL/person/year (MWWS 2009)
MODELLED SAVING		24 kL/person/year	20 kL/person/year	26 kL/person/year
MODELLED SAVING [%]	35%	45%	35%	26%
ACTUAL SAVING	NA	14 kL/person/year	NA	20 kL/person/year
ACTUAL SAVING [%]	NA	25%	NA	20%

[1] (CRCWSC 2017); [2] (CRCWSC 2018); [10] (Beza et al. 2018); [11] (Craig and Richman 2017)

2.5.1 Best Practice – Case Studies

Limited literature is available on the measured performance of mains water reductions for medium-density residential developments around the world. Whilst many developments may outperform the 'Best Practice Case Studies' listed below in modelled outcomes these have not been included as their performance has not been verified. This gap in literature adds to the value of this thesis as it presents the measured performance of mains water reduction strategies at WGV.

Lochiel Park – South Australia

Lochiel Park is a medium-density residential development accommodating around 250 residents (Edwards and Pocock 2009). The state government land developer, Renewal SA, was given the task to reduce resource consumption compared to the average Adelaide home including a 78% reduction for household mains water consumption and an 87% mains water reduction for the entire development (Berry et al. 2013). The water reduction strategies deployed at the development can be seen in Table 5.

Table 5. Water Reduction Strategies Deployed at Lochiel Park - Adelaide

WATER REDUCTION STRATEGY	EXPLANATION
WATER EFFICIENT APPLIANCES	Mandated minimum rated Water Efficiency Labelling Standard (WELs) - Toilet (4 Star – average of 3.1 – 3.5 L/flush) - Dishwasher (4 Star – 6.7 – 14 L per wash) - Showerheads (3 Star – maximum of 9 L/min flow rate)
OUTDOOR EFFICIENCIES	Design Guidelines including native and water conservative front and rear gardens. The design guidelines also recommend that all irrigation is subsurface dripline with spacing of approximately 40cm, as well as including automated control to avoid over watering.
SMART METERING WITH IN-HOME LIVE DISPLAY	In-home touch screen monitoring is available for all residents providing information on total water consumption, as well as a breakdown of alternative sources used. The system also provides residents with the ability to identify any unusual trends leading to early leak detection. The In-home data monitoring is also used as a mechanism for water conservation by alerting residents of their consumption.
RAINWATER HARVESTING	Mandated minimum 1.5kL rainwater tanks, including harvesting rainwater from a minimum of 80% of roof surface area to source hot water systems. Rainwater is heated to a minimum temperature of 60°C to meet Australian standards and to kill Legionella (Standard Australia 2009). The Rainwater source is designed to supply all non-potable hot waters taps and showers.
RECYCLED STORMWATER	A recycled water supply system has been implemented for the development, which captures stormwater from a 190ha urban catchment, the stormwater is then treated through a constructed wetland. It is then provided to residents through a third pipe system that supplies water for toilets, washing machines, and both residential and POS irrigation.
WSUD	Stormwater is collected from the adjacent urban catchment of 70ha before being discharged into the Torrens River.
EXPECTED SAVING IN COMPARISON TO TYPICAL ADELAIDE RESIDENT (75KL/PERSON/YEAR)	A predicted mains water saving of 78% was modelled for Lochiel Park (Edwards and Pocock 2009).

Monitoring and evaluation were undertaken by Chao et al. (2015) which found that a 36% reduction in mains water consumption was attained in comparison to the average Adelaide home (ABS. 2004). The desired mains water reductions of 78% were not achieved. It is understood that this was a result of the stormwater harvesting and recycling scheme not being active at the time of analysis (Chao et al. 2015). Delays in the operation of the recycled stormwater scheme were a result of installation and commissioning issues including the validation of water quality. This led residents to use high quality mains water for non-potable purposes such as irrigation, toilet flushing and washing machine use. Three individual meters were used to measure resident's consumption (mains water, rainwater, rainwater for hot water only).

Aurora Estate - Victoria

Aurora Estate is a 700ha development located North of Melbourne, it accommodates 25,000 residents through 7500 dwellings (Mitchell 2013). The development was designed in the early 2000s for its high residential density which consists of three typologies Terrace (32% of dwellings), Semi-detached (23% of dwellings), detached (45% of dwellings), it has been recognised as a global innovation residential development and best practice of WSUD. Developed by the States Governments sustainable development agency, VicUrban, the project aims to reduce it residential water consumption by 70% in comparison to the typical Melbourne water consumption 75kL/person/year (ABS 2004). The water reduction strategies deployed at the site can be seen in Table 6 (Mitchell 2013).

Table 6. Water Reduction Strategies Deployed at Aurora Estate - Victoria

WATER REDUCTION STRATEGY	EXPLANATION
WATER EFFICIENT APPLIANCES	Mandate the installation of water-efficient appliance for both residential and commercial premises.
OUTDOOR EFFICIENCIES	Landscape uses only native drought tolerant species.
PRESSURE CONTROL	Pressure reducing valve at the meter to restrict the mains water pressure to 500kPa
SMART METERING	Smart metering on water meter (mains, rain, wastewater) providing residents with early detection of any leakages.
RAINWATER HARVESTING	Rainwater is harvested to supplement the mains water source for hot water supplied to homes. The water is captured and stored in above ground water tanks before being pumped to a hot water system that must heat the water to a minimum of 60°C to meet compliance requirements.
RECYCLED WATER	Aurora Estate utilises a third pipe system that supplies water from a centralised wastewater treatment plant for use by resident for all irrigation, toilet use, and washing machines.
WSUD	Stormwater in filtered through raingardens, bioswales and bioretention system that treat the stormwater via filtration through media and vegetation. This system enables greater aquifer recharge then conventional developments.
EXPECTED SAVING IN COMPARISON TO TYPICAL MELBOURNE RESIDENT (75KL/PERSON/YEAR)	A predicted mains water saving of 72% was modelled for Aurora Estate.

RMIT University conducted the water monitoring and analysis for Aurora Estate, which was completed through choosing a small number of homes that have been built and are occupied. These dwellings considered a range of different occupancy ranges that all had smart meters connected to all water meters (mains, rain, and wastewater recycling). Findings suggest that a mains water reduction of 45% has been achieved, with the most effective strategy being the recycled water for irrigation (Binder 2011), whilst rainwater had reduced mains water consumption by 20%, which was a result of using it in hot water systems. Overall residents at Aurora Estate consumed 10% more water in comparison to the typical Melbourne home, which may be a consequence of the rebound effect (Binder 2011).

3 Project Case Study – White Gum Valley (WGV)

White Gum Valley (WGV) is a medium density residential urban infill development in Fremantle, Western Australia. WGV provides an innovative case study of the utilisation of water reduction strategies, including the shared consumption of an alternative water source through a third-pipe system. WGV will eventually comprise around 80 residential dwellings and once completed, it will accommodate approximately 180 residents in a range of typologies as seen in Table 7 (Byrne et al. 2018).

Table 7. Range of Typologies at WGV

TYPOLOGIES	DWELLINGS	RESIDENTS
APARTMENTS	59	112
ATTACHED	2	6
DETACHED	22	62
TOTAL	**83**	**180**

DevelopmentWA initiated the WGV project, aiming to become a precinct-scale demonstration of sustainable urban design and housing. This includes the implementation of water efficiency measures, providing alternative water supplies as a means of reducing mains water reliance, whilst enabling the establishment of a high amenity landscape.

Figure 4. WGV.

3.1 Water Reduction Strategies at WGV

Modelling of mains water consumption at WGV estimated a reduction of 60 – 70% across the various typologies in comparison to a benchmark figure of 106kL per person per year that was established in the Perth Residential Water Use Study 2008/09 (Water Corporation 2010). These savings estimates were based on following water saving initiatives.

Density Savings: Conventional housing in Perth is considered as low density, often with zoning of R20 lots with an average size of 450 m2 (Falconer et al. 2010). Lots at WGV have been designed densities at R35 (medium density) to R80 (high density), with the average lot size being 288m2, this includes 35m2 of paving, 30m2 of turfed area, and 27m2 of garden. Using the Water Corporation regulation of two 10mm watering events per week from September through to May (Water Corporation 2010), it was modelled that a reduction in mains water consumption of 25kL/person/year would be achieved.

Indoor Water Efficiencies (BCA): The Building Code of Australia (BCA) specified minimum water efficient fixtures for all future housing in Western Australia in 2014. The water reduction savings were estimated to be 10kL/person/year.

Indoor Water Efficiencies (+): The developer DevelopmentWA mandated further indoor water efficiencies as seen in Table 8. This was modelled to reduce mains water consumption by a further 7kL/person/year.

Table 8. Summary of Indoor Water Efficiency Requirements at WGV

WATER SAVING FEATURE	EXPLANATION
INTERNAL FITTINGS	
SHOWERHEADS	Mandated WELs 3 Star (< 9L per minute)
TAPS	Design Guidelines recommend WELs 4 Star (6 L per minute)
INTERNAL FIXTURE	
TOILETS	Design Guidelines recommend dual flush toilets
HOT WATER SYSTEMS	Follows BCA – minimum mandated location of less than 20 metres from point of use
BATHS	Design Guidelines recommend low volume bath/spa surface area
INTERNAL APPLIANCES	
DISHWASHER	Mandated WELs 4 Star rated dishwasher or better
WASHING MACHINE	Mandated WELs 4 Star rated dishwasher or better

Landscape Efficiencies: Both Development controls and Design Guidance were provided by DevelopmentWA to residents, this included:

- Providing automatic irrigation controllers that use live rain sensor technology.
- Substrata drip irrigation that are mandated for installation in all garden beds.

Table 9 demonstrates the exact information and requirements of WGV residents.

Table 9. Summary of Outdoor Water Efficiency Requirements at WGV

WATER SAVING FEATURE	EXPLANATION
PLANTS	
PLANT SELECTION	Waterwise/drought tolerant plants selected
MULCH	Design guidelines include waterwise mulch of 5-10cm in all garden beds
DESIGN	
LAWN	Design guidelines mandate lawn areas are less then 50% of garden areas
VERGE	All resident that take up the Sustainability package by DevelopmentWA are required to use native/waterwise plants on verges
IRRIGATION	

WATER SAVING FEATURE	EXPLANATION
IRRIGATION SYSTEM	Mandated substrata drip irrigation for all residential and POS gardens.
MOISTURE SENSOR	Rain sensors are used to turn off automatic watering systems during rain events
OTHER	
POOLS	Pool blankets mandated to reduce evaporation losses

Smart Metering: The 2008/2009 Perth Residential Water Use Study by the Water Corporation found that the average mains water consumption from leaks is 4kL/person/year (Water Corporation 2010). Through the implementation of smart metering for all meters within the precinct will allow for early leak detection leading to the elimination of these losses.

Behaviour Change: The developer DevelopmentWA has provided residents with factsheets on water consumption with the aim of educating residents to reduce their own consumption. It is estimated that savings from behaviour change will be 5kL/person/year.

Rainwater Harvesting: The supply and installation of a 3kL rainwater tank with a pump and controls is available via the developer's sustainability package and have been installed at all detached dwellings that are currently occupied. DGs mandate dual plumbing to toilets and washing machines, provision of enough space for a rainwater tank and sufficient connected roof catchment area.

Community Bore: Groundwater from the superficial aquifer is supplied via a centrally controlled third pipe (purple pipe) system. DGs stipulate that irrigation controllers and individual meters must be installed for optimal efficiency.

3.2 WGV Comparison to Best Practice – Case Studies

Table 10, 11 and 12 compare WGV to the Best Practice Case Studies identified in this Literature review.

Table 10. Comparison of Best Practice Case Studies (Lochiel Park and Aurora Estate) to WGV

	LOCHIEL PARK[3]	AURORA ESTATE[10]	WGV*
TOTAL SIZE	15Ha	700Ha	2.2Ha
LOCATION	South Australia	Victoria	Western Australia
TYPICAL MAINS WATER CONSUMPTION	75 [kL/p/year]	75 [kL/p/year]	106 [kL/p/year]
DWELLINGS	103	8,000	82
POS	4.3Ha	50Ha	0.25Ha
RESIDENTS	247	25,000	179
MAINS WATER CONSUMPTION (MODELLED)	17 [kL/person/year]	21[kL/person/year]	32 [kL/person/year]
MAINS WATER REDUCTION (MODELLED)	78%	72%	70%
MAINS WATER CONSUMPTION (MEASURED)	49 [kL/person/year]	41 [kL/person/year]	TBC

	LOCHIEL PARK[3]	AURORA ESTATE[10]	WGV*
MAINS WATER REDUCTION (MEASURED)	36%	45%	TBC

Table 11. Overview of Best Practice Case Studies compared to WGV including regional context

PROJECT	LOCHIEL PARK[3]	AURORA ESTATE[10]	WGV*
DESCRIPION	Lochiel Park is a 15ha development in South Australia. The project aims for a 78% reduction in mains water consumption through the integration of rainwater and stormwater harvesting as well as water efficiencies and conservation.	Aurora Estate is a 700ha development that accommodates over 25,000 people in Victoria. The development aims to reduce mains water consumption by 72% in comparison to the state typical residents. Mains water reduction strategies include the implementation of rainwater harvesting and a community scale recycled water scheme.	WGV is a 2.2ha infill development project in Western Australia. When fully occupied it will provide accommodation for approximately 180 people. WGV aims to reduce mains water consumption by 60 – 70% in comparison to typical residents in the state. This will be achieved through alternative water supplies such as rainwater harvesting and a community bore.
CLIMATE	Mediterranean	Sub-Mediterranean	Mediterranean
MAIN WATER SOURCE IN THE REGION	Surface Water	Surface Water	Seawater RO Desalination
TYPICAL WATER ENERGY INTENSITY	0.13 – 0.6 kWh/m3	0.13 – 0.6 kWh/m3	3.6 – 5 kWh/m3
TYPICAL RESIDENTIAL WATER CONSUMPTION	75 [kL/p/year]	75 [kL/p/year]	106 [kL/p/year]
TARGETS	78% reduction	72% reduction	60 – 70% reduction
MODELLED PERFORMANCE	17 kL/person/year	21 kL/person/year	32 kL/person/year
MEASURED PERFORMANCE	49 kL/person/year	41 kL/person/year	TBC

Table 12. Best Practice Case Studies Alternative Water Sourcing Compared to WGV

MAIN WATER SOURCES	LOCHIEL PARK[3]	AURORA ESTATE[10]	WGV*
POTABLE	Mains	Mains	Mains
SHOWERS	Rain	Rain	Mains
WASHING MACHINES	Stormwater	Wastewater	Rain
TOILETS	Stormwater	Wastewater	Rain
IRRIGATION	Stormwater	Wastewater	Groundwater

[3] (Sharma et al. 2016); [10] (Beza et al. 2018); * (CRCWSC 2017)

4 Methodology

The following section provides details on the methodology used for data collection and analysis of the mains water reductions at WGV including: Section 3.1 Data Collection Process, and Section 3.2 Preliminary Modelling at WGV. It draws on the findings developed from a review of the literature identified in Section 2. It goes beyond the existing work done by others by investigating the modelled saving with occupancy performance data and evaluating lot-scale and precinct-scale water reduction initiatives.

4.1 Data Collection Process

The design of WGV incorporated the installation of smart meters on all water meters throughout the precinct, enabling high resolution quantitative data to be recorded on the consumption performance. Through the collection of data, a detailed analysis on specific performance metrics within the precinct were possible, enabling the development of robust conclusions based on performance data rather than preliminary modelling which was identified in the above section as a gap in the literature.

A total of 62 smart meter have been installed at WGV for this Thesis, with a remaining 19 pending installation, these are recording parameters such as:

- Mains Water
  - Consumption (kL/dwelling)
  - Flowrate (L/min)
- Bore Water
  - Consumption (kL/dwelling)
  - Flowrate (L/min)
- Rain Water
  - Consumption (kL/dwelling)
  - Flowrate (L/min)
- Infiltration Basin
  - Water level (m)

The remaining smart meter installations are dependent on the completion of construction for the remaining dwellings. Figure 5 identifies the data collection process for all dwellings in WGV through the integration of data loggers onto the water meters. Each water meter at WGV (mains, bore, rain) has an attached data logger that enables remote monitoring through the Outpost Central Platform. Each system component is discussed in further detail in Section 3.2.1.

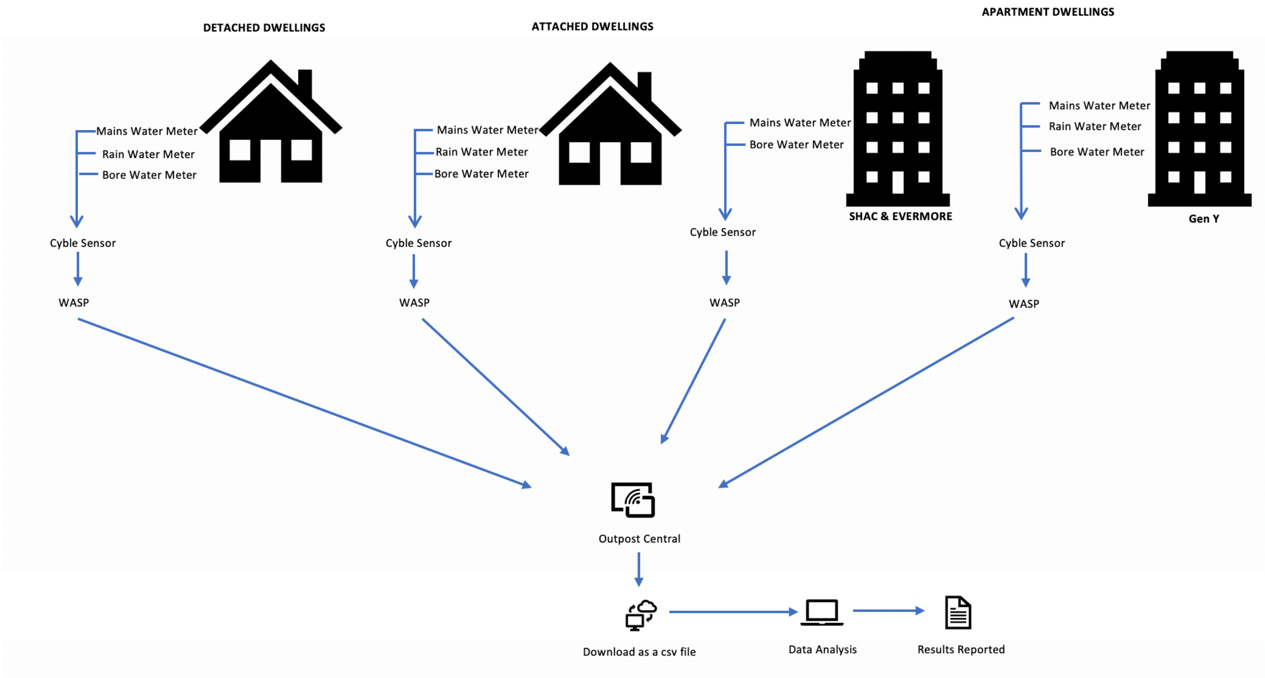

Figure 5. Water Consumption Data Collection Process

4.1.1 Data Logging Equipment

The following section provides a detailed analysis of the data logging equipment used for the monitoring and evaluation section of this thesis. Key equipment includes:

Cyble Sensors

Cyble Sensors are used as the communication module for the WGV project with built in 3V lithium ion batteries. The Cyble Sensors are programmed to take readings on the flowmeter [L/min] and water consumption [kL/day] every fifteen minutes at each lot by reading the pulses on the water meters. Cyble sensors are terminated for either terminal one or two allowing two cybles sensors to be connected to one WASP, this is used when a mains and bore meter are located within close proximity.

WASP

A WASP is Outpost Central's version of a wireless smart water meter providing up-to-date water consumption data to users. The WASP's transfer's data to cloud-hosted servers via a 3G network, data is uploaded to the server in which the data can be downloaded as a CSV file for analysis. WASP consist of two counters, which enables the smart meter to receive data from two separate water maters. Most dwellings at WGV contain one WASP between their Mains and Bore water meters.

The WASP are initially activated through termination via a magnet, a LED light then provides detail on the status of the WASP. The following message a relayed to the users via the LED light, this includes:

- Blue: Indicates the WASP is attempting to find a cellular operator for connection;
- Red: The WASP has not been successfully connected to a cellular network and therefore no data would have been received;
- Orange: One of the counters on the WASP have not been correctly terminated.
- Green: The WASP has successfully connected to a cellular network and the data has been uploaded.

Once a green light has been identified then the data is relayed back to the Outpost Central platform and is ready for analysis.

Outpost Central

Outpost Central is the main platform used for water consumption data collection and monitoring at the WGV site. It connects meters and sensors to a webpage where the data can be extracted through Microsoft Excel for further analysis.

Appendix 7.3 provides an overview of the Outpost Central Platform that reports the status of the WASP's installed at the WGV site.

4.1.2 Data Logging Installation at WGV

Outpost Central's smart meter configuration has been utilised as the data logging equipment for WGV. Two types of water meters have been employed within the WGV precinct, including both Elster and Itron water meters. Itron water meters have been used for mains, bore and rain sites in all single residential dwellings (detached and attached). A combination of both Elster and Itron meters have been used within the apartment dwellings at WGV.

Cyble sensors are then connected directly to the Itron water meters, whilst pulse probes are fitted to the Elster meters to 'read' pulses that correlate to the same parameters.

The data logging of the property meters (mains water and community bore services) and the rain water tanks for the detached lots is via WASP data loggers using the 3G mobile network to transmit data to the Outpost Central server. The data logging of individual apartment water use (e.g. Gen Y, SHAC and Evermore) is done at the building scale using Schneider ComX 510 loggers and gateway servers.

The WASP's then relay the data collected to the Outpost Central Platform for further analysis. During the implementation phase, manual readings were taken of all functioning meters within the site to verify remote readings as they came on line. Figure 6 provides a schematic overview of the data collection process.

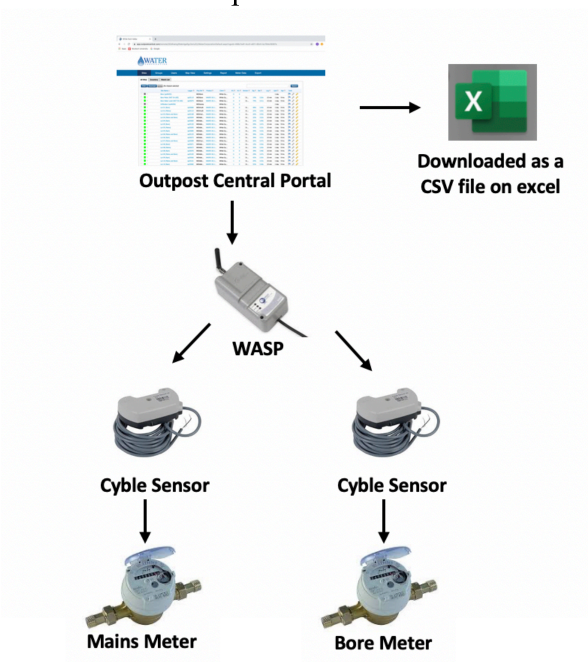

Figure 6. Typical WGV Smart Meter Configuration

4.1.3 Data Loggers Installed at WGV

Data loggers have been installed at twenty one sites, with six sites still in construction and one not taking part in the study. Of the twenty one sites with data loggers installed, sixteen have been included in this study, with the remaining five sites being excluded due to short data ranges or data not successfully being verified. Therefore, all data included in this thesis has been verified and data has been recorded for a minimum of one hundred and fifty days. These eligible sites include twelve detached dwellings, one attached dwellings, and three apartments. A detailed summary of the Data loggers installed at WGV can be seen in Table 13.

Table 13. Summary of Data Loggers Installed at WGV

REFERENCE	METER TYPE	COMMENT / STATUS
DETACHED 1	Mains	Installed on the 23/11/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Bore	Installed on the 23/11/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Rain	Installed on the 01/09/2019. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 2	Mains	Installed on the 31/08/2018. Data has been received continuously since installation. The data has been used in this thesis.
	Bore	Installed on the 3/08/2018. The community bore was not correctly connected until March 2019. Therefore, no data was received until 08/03/2019.
	Rain	Installed on the 31/08/2018. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 3	Mains	Installation date is unknown. Data has been received since 21/07/2019. The data has been used in this thesis.
	Bore	Installation date is unknown. A delayed connection to the community bore for Detached 3 occurred on the 05/03/2019. Data has been received since that date. The data has been used in this thesis.
	Rain	Installation date is unknown. Data has been received since 21/07/2019. The data has been used in this thesis.
DETACHED 4	Mains	Installation date is unknown. Data has been received since 19/01/2018. The data has been used in this thesis.
	Bore	Installation date is unknown. Data has been received since 19/01/2018. The data has been used in this thesis.
	Rain	Installation date is unknown. Data has been received since 19/01/2018. The data has been used in this thesis.
DETACHED 5	Mains	Installation date is unknown. Data has been received since 19/01/2018. The data has been used in this thesis.
	Bore	Installation date is unknown. Data has been received since 19/01/2018. The data has been excluded from this thesis due to inconsistences between manual reads and the data received via the online platform.
	Rain	Installed on the 01/09/2019. Data has been received continuously since installation. Detached 6's data has not been included in this thesis due to a short period of data collection.
DETACHED 6	Mains	Installation date is unknown. Data has been received since 19/01/2018. The data has been used in this thesis.

REFERENCE	METER TYPE	COMMENT / STATUS
	Bore	Installation date is unknown. Data has been received since 22/01/2018. The data has been used in this thesis.
	Rain	Installation date is unknown. Data has been received since 31/08/2018. Detached 6's data has not been included in this thesis due to a short period of data collection.
DETACHED 7	Mains	Installed on the 02/02/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Bore	Installed on the 02/02/2019. Detached 7 is currently not connected to their bore meter.
	Rain	Installed on the 30/04/2019. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 8	Mains	Installed on the 09/01/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Bore	Installed on the 09/01/2019. Detached 8 is currently not connected to their bore meter and therefore isn't included in this thesis.
	Rain	Installed on the 20/05/2019. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 9	Mains	Installed on the 31/08/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Bore	Installed on the 31/08/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Rain	Installed on the 31/08/2019. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 10	Mains	Installed on the 11/09/2018. Data has been received continuously since installation. The data has been used in this thesis.
	Bore	Installed on the 01/02/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Rain	Installed on the 11/09/2018. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 11	Mains	Installed on the 04/02/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Bore	Installed on the 04/02/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Rain	Installed on the 23/11/2018. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 12	Mains	Installed on the 09/11/2019. Data has not been included in this thesis due to the data not being successfully validated.
	Bore	Installed on the 09/11/2019. Installed on the 09/11/2019. Data has not been included in this thesis due to the data not being successfully validated.
	Rain	Installed on the 09/11/2019. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 13	Mains	Installed on the 31/08/2019. Data has been received continuously since installation. Data has not been included in this thesis due to the data not being successfully validated.
	Bore	Installed on the 31/08/2019. Detached 13 is currently not connected to their bore meter.
	Rain	Installed on the 19/01/2019. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 14	Mains	Installed on the 13/01/2019. A mix up with data loggers has caused the data to be sent to a contractor. The data is currently not available for this thesis.

REFERENCE	METER TYPE	COMMENT / STATUS
	Bore	Installed on the 13/01/2019. Installed on the 13/01/2019. A mix up with data loggers has caused the data to be sent to a contractor. The data is currently not available for this thesis.
	Rain	A Rain water tank has currently not been installed.
DETACHED 15	Mains	Installed on the 21/08/2019. Data has been received since the installation date. Detached 15's data has not been included in this thesis due to a short period of data collection.
	Bore	Lot 13 is not currently connected to the bore meter.
	Rain	A Rain water tank has currently not been installed.
DETACHED 16	ALL	Detached 16 has decided to not take part in the Sustainability package offered by DevelopmentWA.
DETACHED 17	Mains	Installed on the 21/08/2019. Data has been received continuously since installation. Detached 17's data has not been included in this thesis due to a short period of data collection and still being in the construction phase.
	Bore	Installed on the 21/08/2019. Data has been received continuously since installation. Detached 17's data has not been included in this thesis due to a short period of data collection and still being in the construction phase.
	Rain	Installed on the 21/08/2019. Data has been received continuously since installation. Detached 17's data has not been included in this thesis due to a short period of data collection and still being in the construction phase.
DETACHED 18	Mains	Installed on the 19/03/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Bore	Installed on the 01/02/2019. The data has been excluded from this thesis due to inconsistences between manual reads and the data received via the online platform.
	Rain	Installed on the 31/03/2019. Data has been received continuously since installation. The data has been used in this thesis.
DETACHED 19	ALL	Currently in construction.
DETACHED 20	ALL	Currently in construction.
DETACHED 21	ALL	Currently in construction.
DETACHED 22	ALL	Currently in construction.
ATTACHED 1	Mains	Installation date is unknown. Data has been received since 19/01/2018. The data has been used in this thesis.
	Bore	Installation date is unknown. Data has been received since 08/05/2019. The data has been used in this thesis.
	Rain	Installed on the 31/08/2018. Data has been received continuously since installation. The data has been used in this thesis.
APARTMENT 1	Mains	Installed on the 25/03/2019. Data has been received continuously since installation. A unique data logger (dove-tailed reed pulsar) was required due to the meter type. The data has been used in this thesis.
	Bore	Installed on the 18/12/2019. Data has been received continuously since installation. The data has been used in this thesis.
	Rain	No Rain water tank is installed for Apartment 1.

REFERENCE	METER TYPE	COMMENT / STATUS
APARTMENT 2	Mains	Installed on the 21/07/2017. Data has been received continuously since installation. The data has been used in this thesis.
	Bore	Installed on the 23/08/2017. Data has been received continuously since installation. The data has been used in this thesis.
APARTMENT 3	Mains	Installation date is unknown. Data has been received since 21/07/2017. The data has been used in this thesis.
	Bore	Installation date is unknown. Data has been received since 21/07/2019. The data has been used in this thesis.
	Rain	Installation date is unknown. The data is collected through the Solar Balance platform.
APARTMENT 4	ALL	Currently in construction.
APARTMENT 5	ALL	Currently in construction.

4.1.4 Verification of Data Logging Equipment

The verification of the data loggers took place over an 8-month period starting in January 2019 and concluding in August 2019. This was completed through conducting fortnightly manual reads of both Mains and Bore water meters at the site. The manual reads were then compared with the data being received through the Outpost Central Portal in which a difference of approximately 2% was recorded on average for the whole site, therefore verifying the data being received through the online portal. All mains, bore and rain water data used in this thesis has been collected through the online Outpost Central Portal, with the exception of Gen Y's rain water consumption data which was provided by Balance Utility Solutions (Balance). Balance collects rain water data from Gen Y every 15 minutes including the flowrate (L/min) and daily water consumption (kL/day) (Byrne et al. 2019).
Almost all rainwater tanks installed at WGV are located behind the resident's private fencing making verification of the rain water meter difficult. The rainwater data has not been verified however, was assumed to be classed as acceptable for use based on the verification of mains and bore water meters. The verification of mains and bore data can be seen in Appendix 8.4.

4.2 Preliminary Modelling

This section provides an overview of the modelling completed by JBA for detached, attached and apartment dwellings at WGV. The apartment and attached dwellings were modelled with the same initiatives as detached dwellings however have different mains water saving expectancies due to the variation in the typology. These modelling outputs are provided to indicate where the mains water savings where predicted to come from, and to what degree.

4.2.3 Detached Dwellings

There are twenty-two detached residential dwellings on 'green title' lots ranging in size from 250m2 – 350 m2. To date, all detached lot owners have agreed to install a rainwater tank (minimum 3kL) plumbed to toilets and washing machine as part of a DevelopmentWA sustainability package that covers the cost of the system (tank, pump and controls). In addition, each lot is serviced by a metered connection from the community bore irrigation scheme. All meters installed at the detached lots are Itron water meters. The following chart shows (Figure 7), for the Detached Dwellings, the stepwise reduction contributed by each of the initiatives described in the previous section.

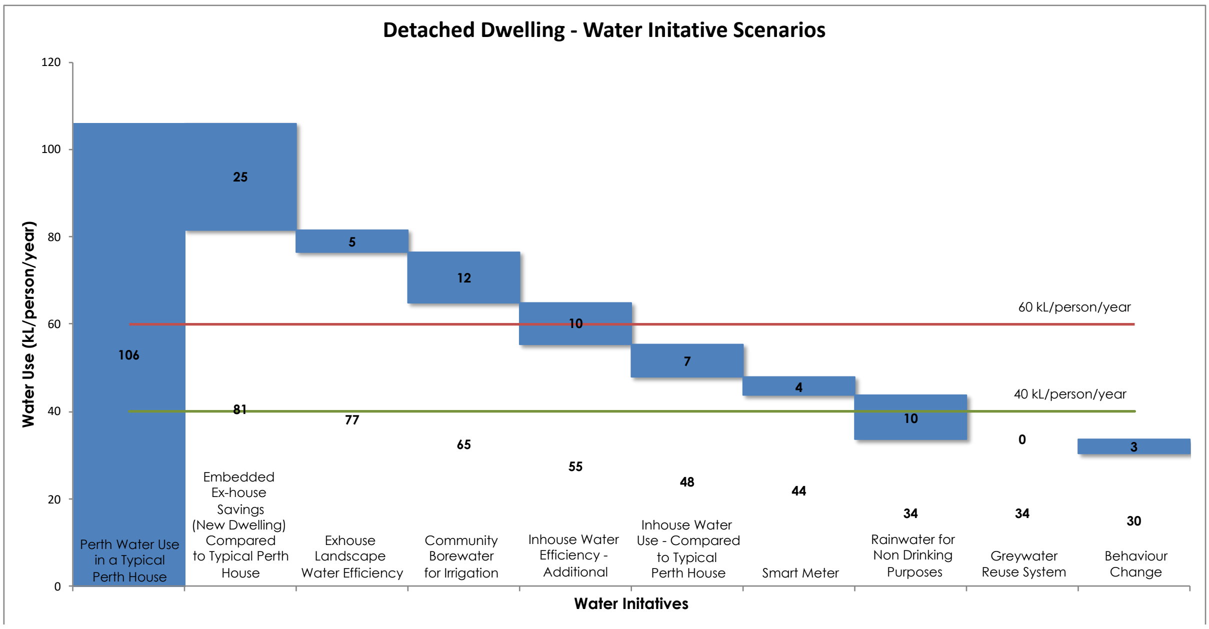

Figure 7. Modelled Water Saving for Detached Dwellings (Source: JBA)

4.2.2 Attached Dwellings

There is one duplex site at WGV, comprising of two attached dwellings. They share a common rainwater system (5kL) and their mains water supply is connected at a single meter. They are connected to the shared bore for irrigation supply, again at a single point of supply for the site. All meters installed are Itron water meters. The following chart shows (Figure 8), for the Attached Dwellings, the stepwise reduction contributed by each of the initiatives described in the previous section.

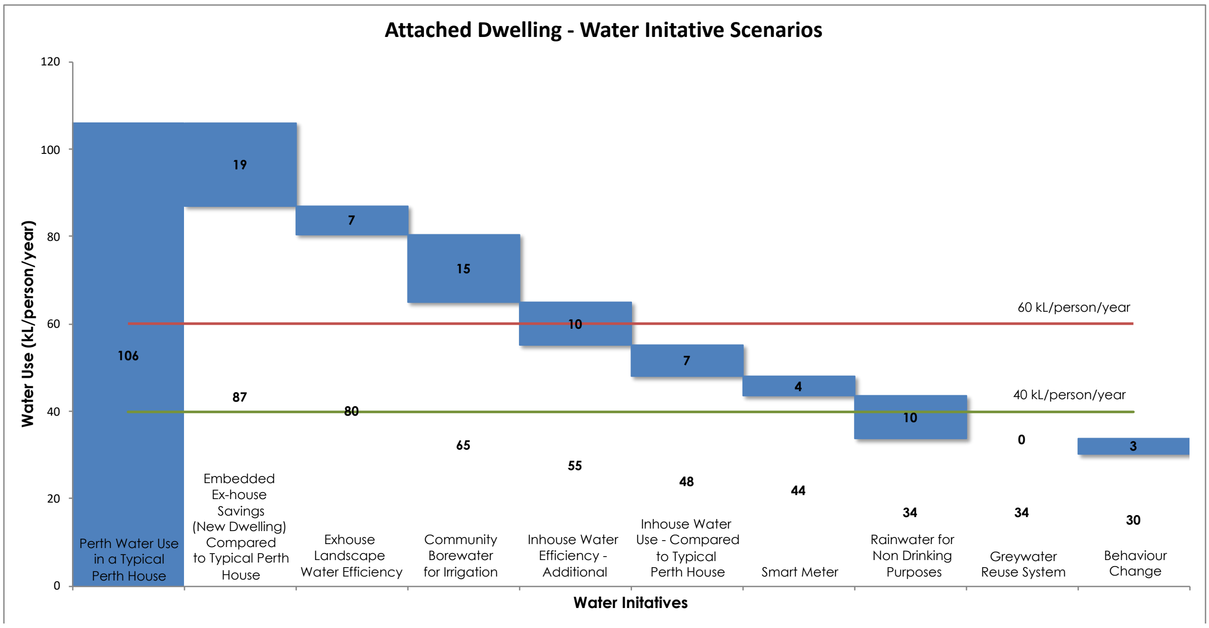

Figure 8. Modelled Water Savings for Attached Dwellings (Source: JBA)

4.2.3 Apartments

There are currently three apartment complexes at WGV. These include:

- SHAC (Sustainable Housing for Artists and Creatives) apartments which include 12 dwellings that are currently fully occupied, plus two studios used for shared work spaces.

- Evermore apartments (24 dwellings) which are now fully occupied.
- Gen Y Demonstration House (Gen Y) which consists of three apartments that are all occupied.

SHAC and Evermore apartments do not have access to any rainwater for internal uses. Gen Y has a shared 10kL rainwater tank underground in the central courtyard of the complex which supplies water for washing machines and toilet flushing, with each apartment's consumption of the rainwater supply individually metered. Submetering of the mains and rains water (non-potable) is via Itron meters. A common connection to the community bore supply is also via an Itron meter.

The following chart shows (Figure 9), for Apartment dwellings, the stepwise reduction contributed by each of the initiatives described in the previous section.

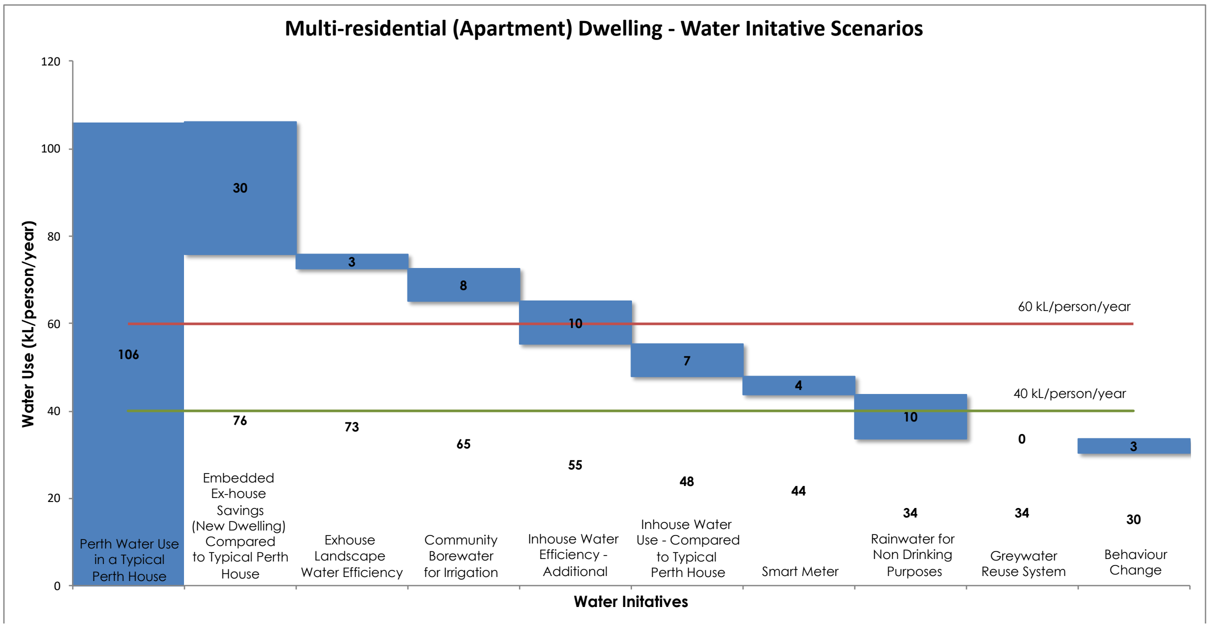

Figure 9. Modelled Water Savings for Apartments (Source: JBA)

4.2.4 WGV Precinct Water Balance

JBA completed the preliminary water balance for the site as seen in Figure 10. The modelling demonstrates that the precinct is expected to consume approximately 4,500 kL/year of Mains water which is the equivalent of 21 kL/person/year, 500 kL/year of rainwater resulting in 10 kL/person/year. It is expected that 48% of the designated community bore allocation will be consumed by residents for irrigation whilst 52% will be consumed for the precinct's public open space. Resulting in 5,000 kL/year or 15 kL/person/year.

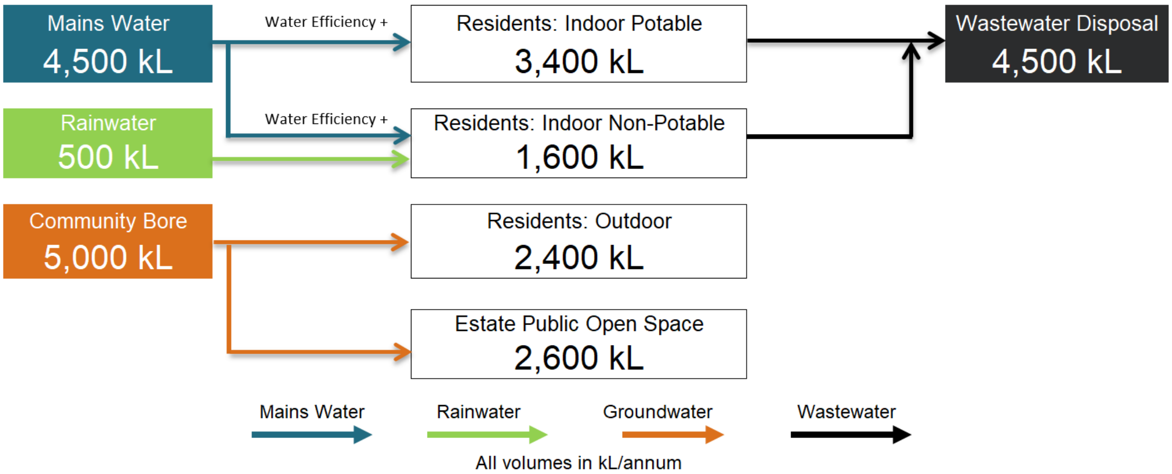

Figure 10. WGV Modelled Water Balance

5 Results and Discussion

The following section provides a detailed discussion on the results recorded at WGV. This section will provide closure on the whether the preliminary modelling meets the performance data providing conclusions on whether WGV has been successful in regard to the implementation of water reduction strategies.

5.1 Overview of WGV Dwellings Water Consumption

WGV set out to reduce mains water consumption by 72% in comparison to the typical Perth home (Water Corp). This paper reports on water consumption levels for dwellings in WGV from January 2016 to October 2019. Figure 11 presents the results for residential water consumption for the performance data.

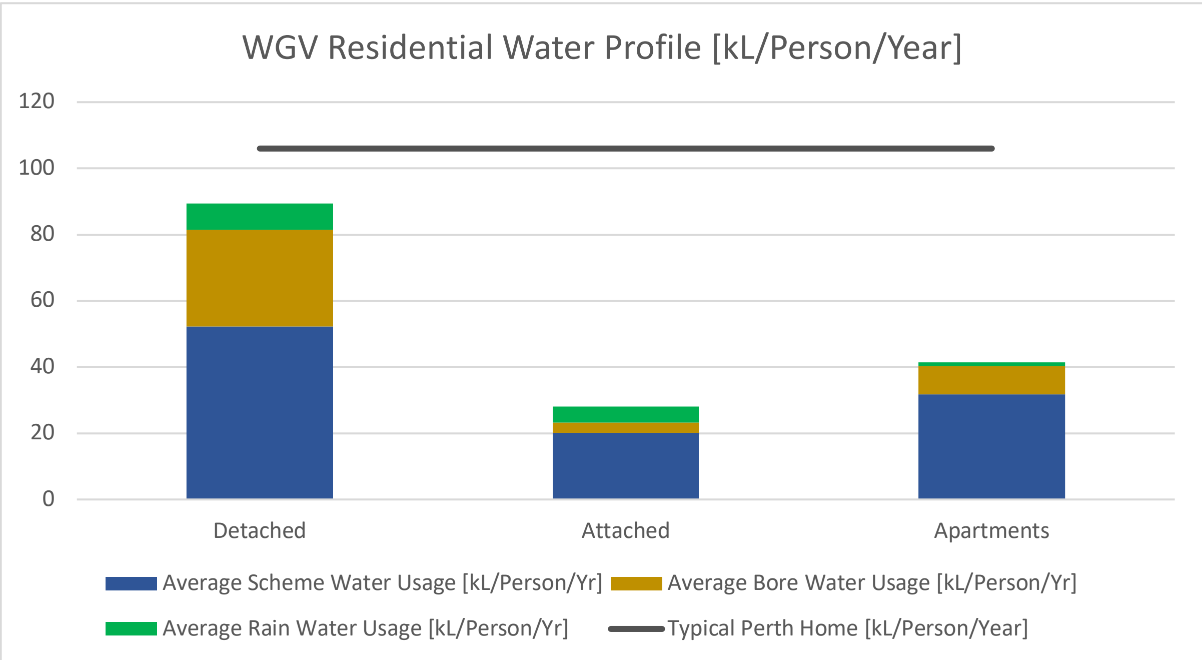

Figure 11. Water Consumption at WGV for the three typologies (Detached Dwelling, Attached Dwelling and Apartments)

The annual water consumption for a detached resident at WGV is 89kL/person/year, made up of 52kL/person/year mains water, 29kL/person/year of bore and 8kL/person/year of rain water. This results in a mains water reduction of 54kL/person/year or 51% reduction to the typical Perth home.

Attached resident's living within WGV, consume on average 28kL/person/year consisting of 20kL/person/year mains water, 3kL/person/year bore water and 5kL/person/year rainwater. In comparison to the typical Perth resident attached dwellings reduce their mains water consumption by 81%.

Apartment resident's total annual water consumption is 41kL/person/year, consisting of 32kL/person/year mains water leading to a mains water reduction of 70%. The remaining water consumption is made up of 9kL/person/year bore water and 1kL/person/year of rain water.

The average total water consumption for the precinct is 56kL/person/year, consisting of 38kL/person/year mains water, 15kL/person/year bore water and 7kL/person/year rain water, as seen in Table 14.

A 64% reduction in mains water consumption has been achieved for the whole precinct, demonstrating that the preliminary modelling completed by JBA was accurate as a mains water reduction was within 10% of the predicted value (72%).

Table 14. Water Sources breakdown of Three Typologies at WGV

Typology	Mains Water Consumption [kl/person/year]	Bore Water Consumption [kl/person/year]	Rain Water Consumption [kL/Person/year]	Total Water Consumption [kL/Person/year]	Total Water Reduction in comparison to Typical Perth Home [%]
Detached	52	29	8	89	16%
Attached	20	3	4	27	74%
Apartments	32	9	1	40	61%
Precinct Weighted Average	38	15	7	56	47%

Table 15. WGV Mains Water Consumption over Three Typologies

Typologies	JBA Preliminary Modelling		Measured Performance Data	
	kL/Person/Year	**Mains Water Reduction [%]**	**kL/Person/Year**	**Mains Water Reduction [%]**
Detached	30	72%	52	51%
Attached	30	72%	20	81%
Apartments	30	72%	32	70%
Average	30	72%	38	64%

5.1.1 Detached Dwellings

The data collection for the detached dwellings at WGV consisted of eleven dwellings, seven dwellings recorded data for all water sources (mains, bore and rain), whilst four dwellings only collected data from two sources (either mains and bore or mains and rain). This was a result of some detached dwellings deciding not to connect to the community bore whilst others had yet to install their rainwater tank.

A large variation in water consumption was seen between the detached dwellings. As seen in Figure 12, Detached 1 was the only dwelling in WGV with validated data that's total water consumption was above the typical Perth residents and was the highest mains water consumer and also the highest overall water consumer using up to 110kL/person/year made up of approximately 79% mains water. However, its mains water consumption was approximately 18% lower than the Perth average. Detached 7 was the lowest water consumer of the detached dwellings consuming approximately 55kL/person/year consisting of 47kL/person/year of mains water and 8kL/person/year of rain water whilst at this stage they had decided not to connect to the community bore. Detached 6 had the lowest mains water consumption out of the detached dwelling, consuming approximately 36kL/person/year of mains water, a reduction of 66% to the typical Perth resident. Figure 12 provides an overview of the detached dwelling results. The detached dwellings were the highest water consumers of the three typologies, consuming approximately 200% more water than attached dwellings and 108% more water than WGV apartment residents. These results can be explained due to the difference between average lot sizes over the three typologies. Detached lots have the largest lot size per person with an average of 105m^2 in comparison to 49m^2 for attached dwellings and 55m^2 for apartments. From this it can be assumed that detached lots have larger gardens and more water consuming appliances and fixtures then the attached and apartment dwellings.

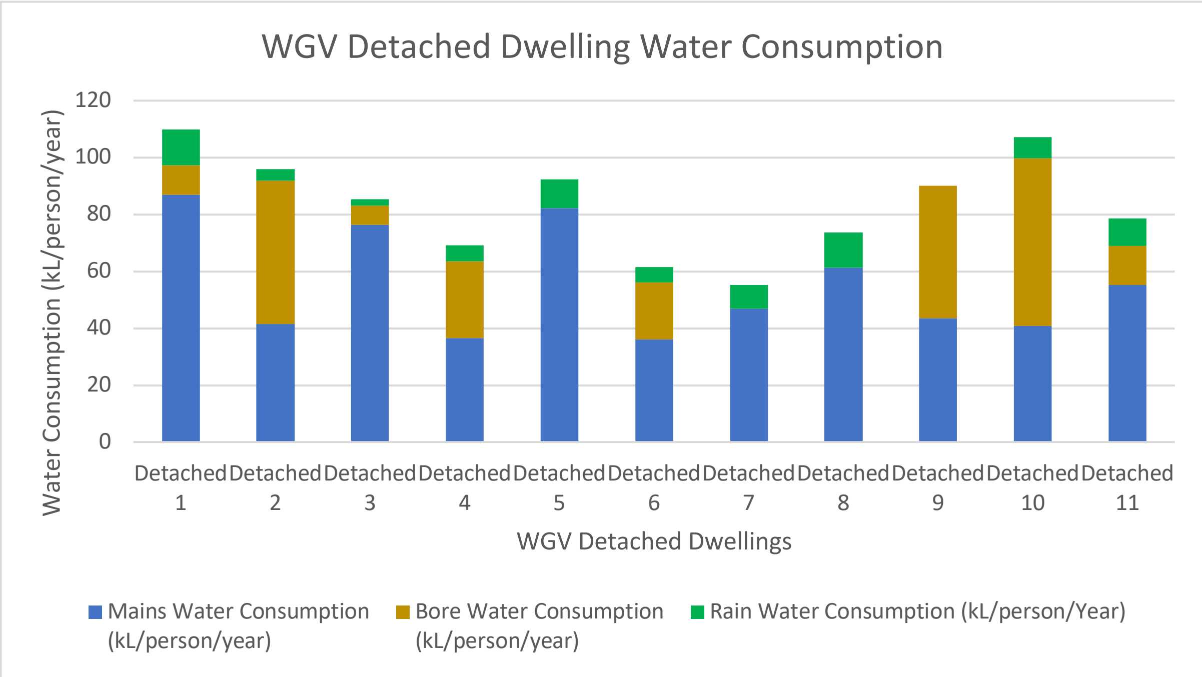

Figure 12. WGV Detached Dwellings Water Consumption Overview

Preliminary modelling anticipated detached dwellings to consume approximately 30kL/person/year of mains water, 12kL/person/year of bore water for irrigation purposes and 10kL/person/year of rain water for non-potable water sources. However, the performance data demonstrates that no detached dwellings were within in 10% of the anticipated water consumption levels with detached dwellings using approximately 60% more mains water, 83% more bore water and 22% more rain water then the preliminary modelling.

The increase in bore water data in comparison to the modelled figures has been recognised as a result of detached residents not changing their irrigation controller setting from the initial establishment phase of their gardens. Figure 13 demonstrates that there has been no decrease in the average bore water consumption that would have been expected as gardens begun to establish themselves. It is recommended that further data collection is recorded to see if resident bore water consumption begins to reduce as more gardens become established. NOTE: Only three detached dwellings (Detached 1, Detached 6, and Detached 8) recorded data over both 2018 and 2019 and have been used in Figure 13.

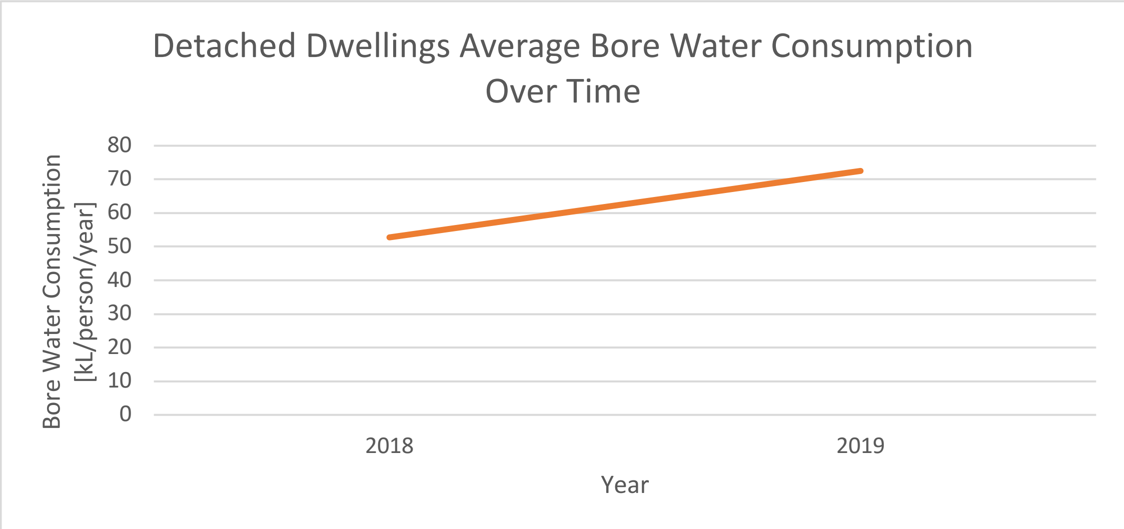

Figure 13. Average Bore Water Consumption over Time for Detached Dwellings at WGV

Looking further into the consumption on bore water for detached residents within WGV it was identified that many residents were not turning off their reticulation system during the winter months, the consumption trend can be seen in Figure 14. According to the Water Corporation all reticulation systems are supposed to be turned off during the winter months (June, July, and August). However, this is not the case for WGV detached dwellings with the irrigation systems still consuming a minimum of approximately 3kL/dwelling in the month of July.

The over consumption of bore water in comparison to the preliminary modelling figures can be justified as a lack of education in regard to behavioural changes. If further water saving education programs are provided to residents it could lead to further reductions in total water consumption for detached residents. This would include educating residents on the water requirements for their gardens in particular the reduction of irrigation following the gardens establishment period and secondly educating residents on turning irrigations systems off during winter months whilst reducing irrigation supply during the other non-summer months.

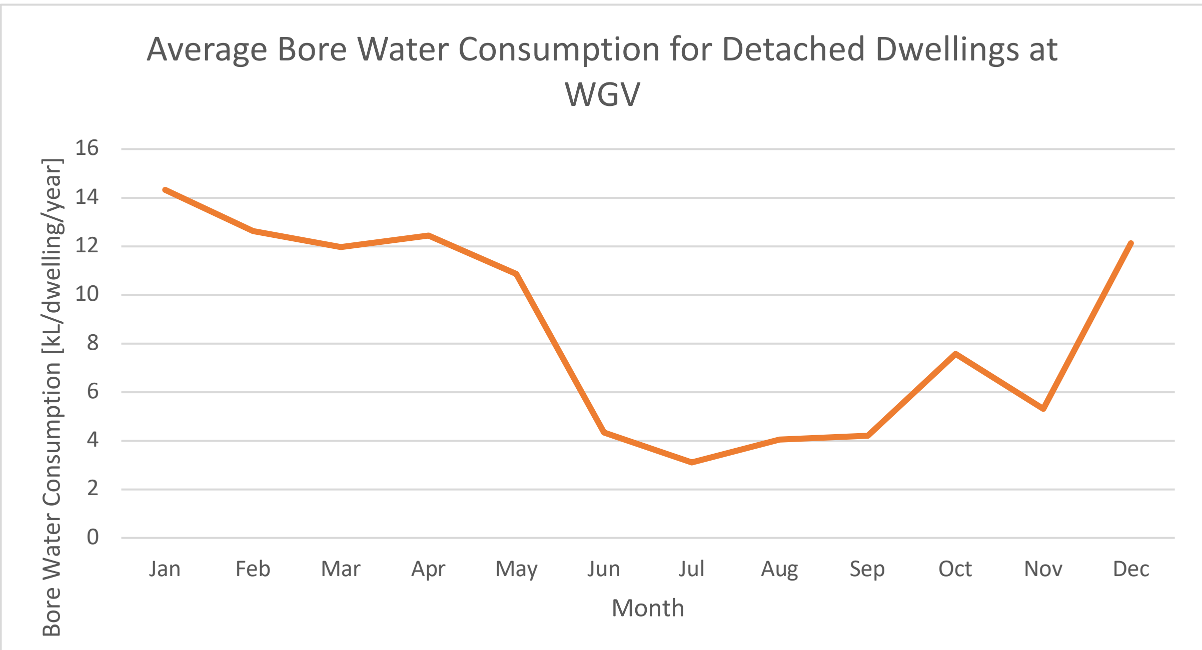

Figure 14. Monthly Bore Water Consumption for Detached Dwellings at WGV

Detached dwellings consume approximately 33% of their total water consumption for irrigation purposes which is a 7% reduction to the typical Perth home.

Detached dwellings at WGV consumed approximately 8kL/person/year of rain water through the implementation of minimum 3kL rain water tanks. The performance data demonstrated a 25% reduction from the preliminary modelling which estimated detached dwelling residents would consume 10kL/person/year of rain water. Figure 15 presents the modelled annual rainfall [mm] which used data from the last 25 years in comparison to the actual annual rainfall for the data collection period. The modelled value was 731mm/year in comparison to the actual average rainfall over the data collection period of 706mm/year, resulting in a reduction of 4% which can provide a possible explanation for the variation of actual rainwater consumption in comparison to the preliminary modelling.

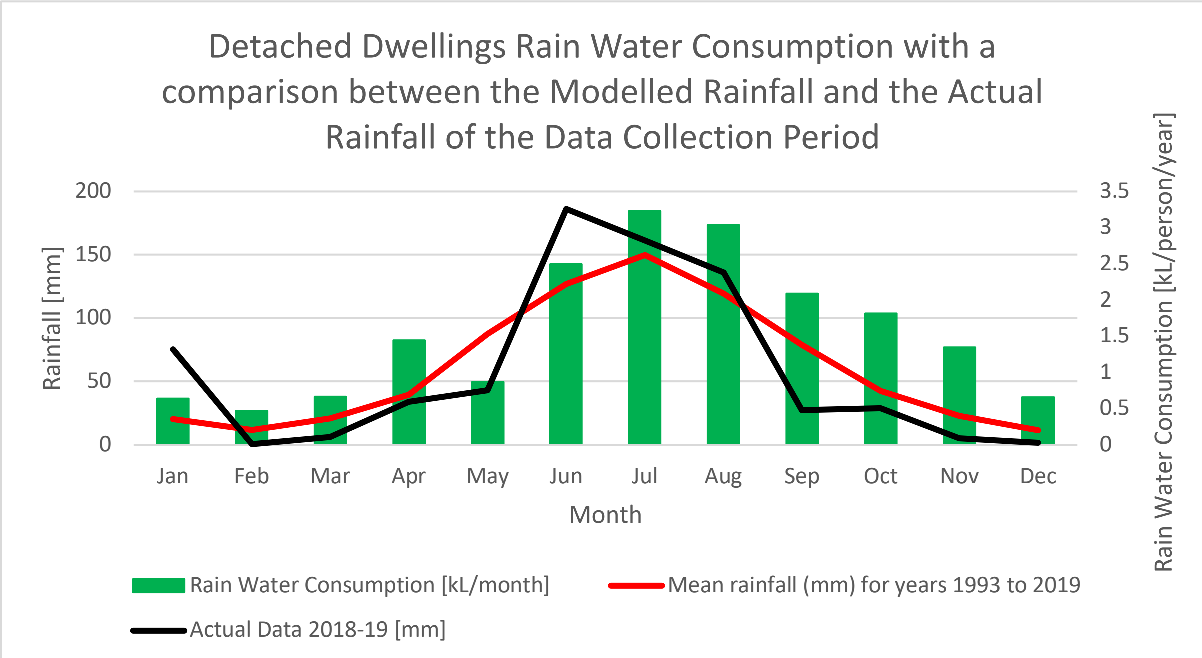

Figure 15. Detached Dwellings Rain Water Consumption with a comparison between the Modelled Rainfall and the Actual Rainfall of the Data Collection Period

Further understanding of the performance of the rain water tanks could include auditing their performance as it can be seen in Figure 16, that some dwellings are not recording any consumption during rainfall events leading to the assumption that their rainwater tanks are not functioning correctly.

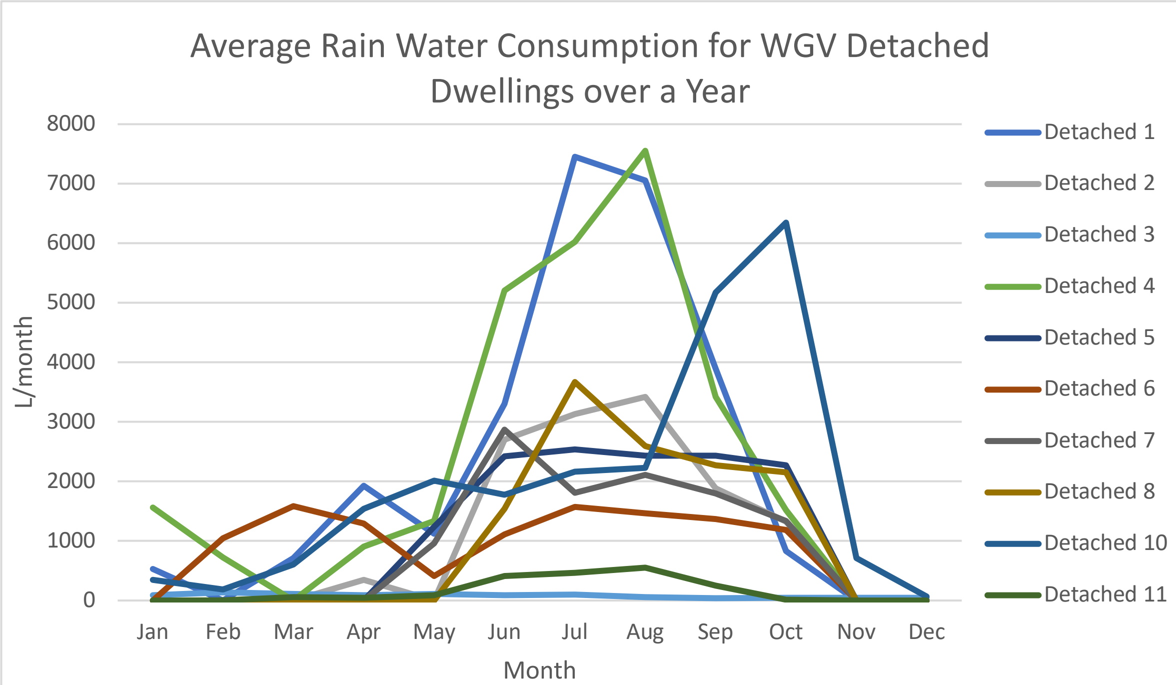

Figure 16. Detached Dwelling Average Rain Water Consumption over a Year

5.1.2 Attached Dwellings

The data collection for the attached dwellings at WGV was collected from August 2018 until October 2019. The attached dwelling consumed the least amount of water per person per year out of the three typologies located within the precinct. Residents of attached dwellings consumed 69% less water than detached dwellings and 30% less than apartments leading to a total water consumption of 28kL/person/year. The preliminary modelling estimated that the attached dwelling would consume 55kL/person/year of water made up of 30kL/person/year of mains water, 15kL/person/year of bore water and 10kL/person/year of rain water. The actual performance data was a 49% decrease then the modelled consumption, resulting in a 33% reduction in mains water, 80% reduction in bore water and a 60% reduction in rain water in comparison to the modelled values. The comparison between the attached dwellings modelled data and the performance data can be seen in Figure 17.

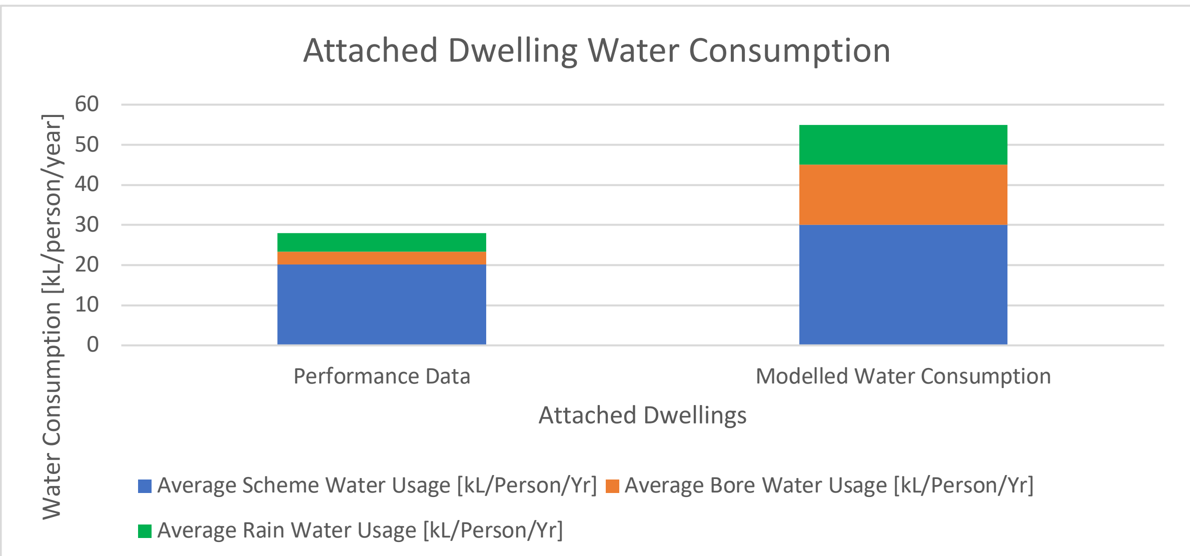

Figure 17. Attached Dwelling Water Consumption in Comparison to the Preliminary Modelling

The attached dwelling water results demonstrate a major reduction in comparison to the typical Perth home with a 74% reduction in total water consumption and an 81% reduction in mains water consumption. Whilst comparing the attached dwelling to typical Perth homes with bores it can be recognised that attached residents reduce their overall consumption by 89%. Figure 18 provides an overview of the water profile of attached dwellings in WGV.

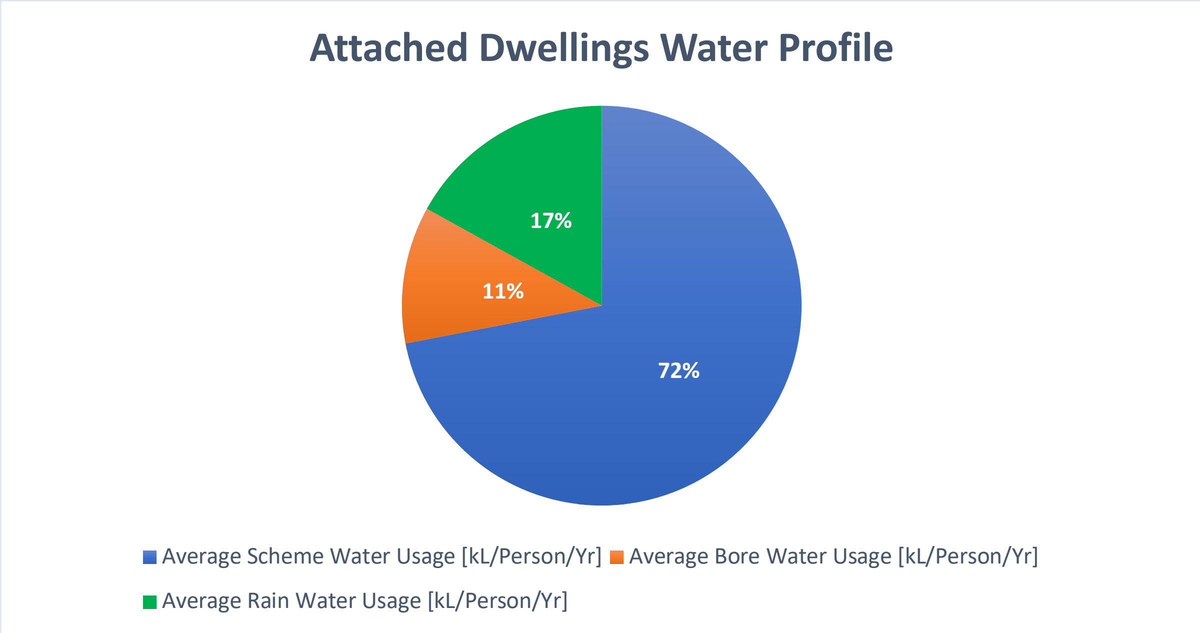

Figure 18. Attached Dwelling Water Breakdown based on Performance data

The results of the attached residents can be explained through the high density living associated with attached dwellings or duplexes, which was predicted to have water saving benefits in the preliminary modelling. Attached residents have the smallest area per person within the precinct with an average of 49m^2 per person. This results in residents of attached dwellings sharing their water consumption between all residents within the duplex including shared irrigation demands etc.

Figure 19 demonstrates that Attached dwellings consumed water during the winter months of 2018, however during the 2019 winter month is can be seen that the reticulation system was turned off as required by the Water Corporation. Figure 19 also demonstrates that the bore water consumption is declining over time, this can be explained through the attached residents understanding that their gardens have established leading to a reduction in their irrigation demand.

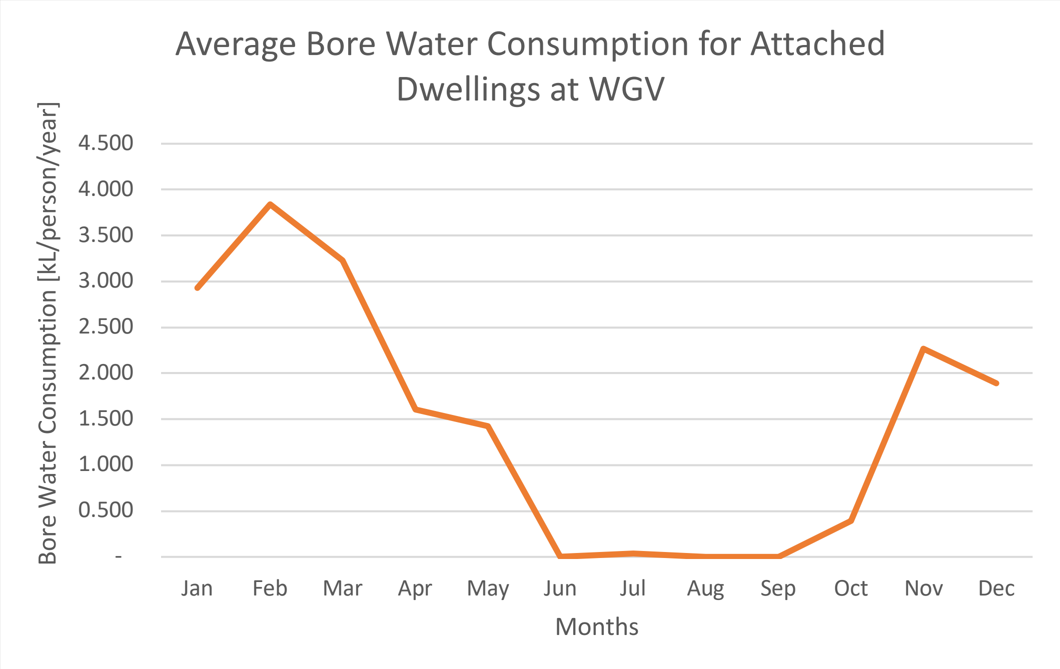

Figure 19. WGV Attached Dwellings Average Bore Water Consumption over Time

Figure 20 presents the rainwater consumption (L) for the attached dwelling at WGV against the modelled and actual annual rainfall (mm). As explained in the detached dwellings section above, a decrease in annual rainfall between the modelled and the actual data occurred, this has directly impacted the consumption of rainwater for attached residents.

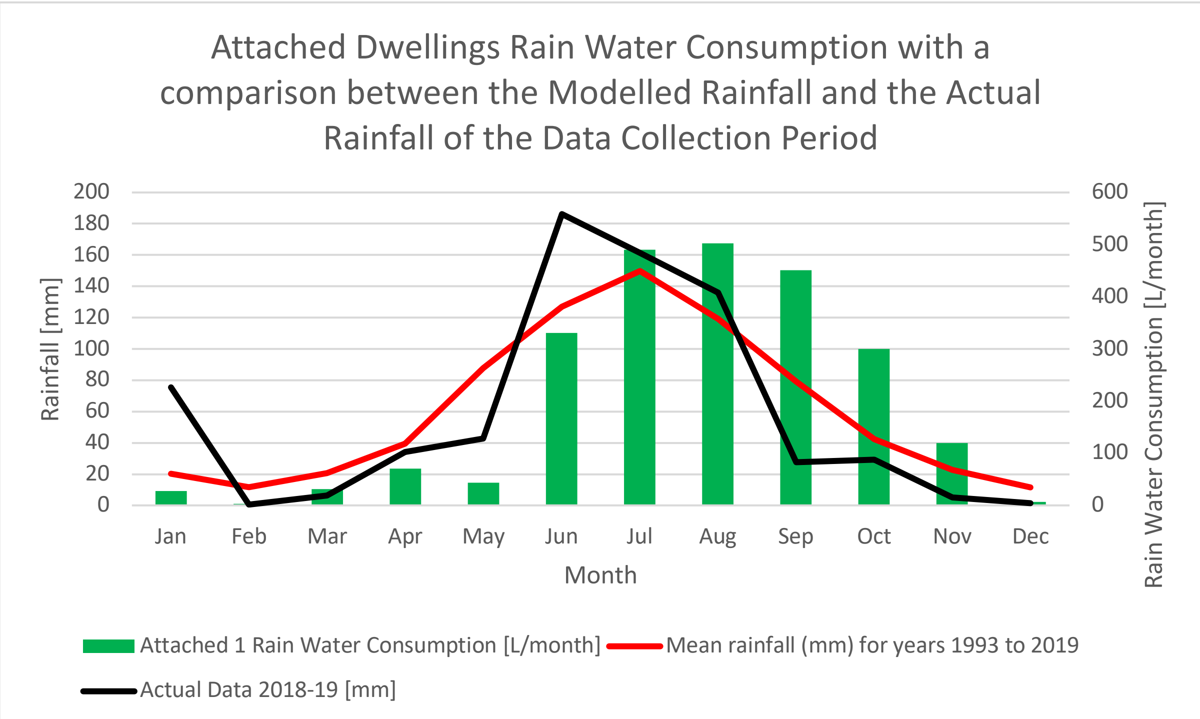

Figure 20. WGV Attached Dwellings Average Rainwater Consumption

5.1.3 Multi-residential (Apartment) Dwellings

Apartment residents are the second lowest water consumer out of the three typologies residing at WGV. Gen Y (Apartment 3) was the lowest apartment mains water consumer on average using approximately 29kL/person/year which was to be expected due to Gen Y being the only apartment with access to rain water (13kL/person/year). Whilst SHAC (Apartment 2) was the largest apartment water consumer with an average of 35kL/person/year. Overall, residents living in an apartment at WGV reduce their mains water consumption by 70% in comparison to the typical Perth home. The apartments at WGV were relatively consistent for their mains water consumption with all three apartments within 20% of each other (Evermore = 31kL/person/year, SHAC = 35kL/person/year, and Gen Y = 29kL/person/year). Whilst the bore consumption varies quiet significantly between all three apartments (Evermore = 9kL/person/year, SHAC = 2kL/person/year, and Gen Y = 14kL/person/year). It has been recognised that SHAC apartments have private courtyards that are hand watered by residents using mains water from their own metered supply. Only common areas are irrigated off the community bore, this can explain SHAC's low consumption of bore water. Figure 21 provides an overview of the three apartment's water consumption.

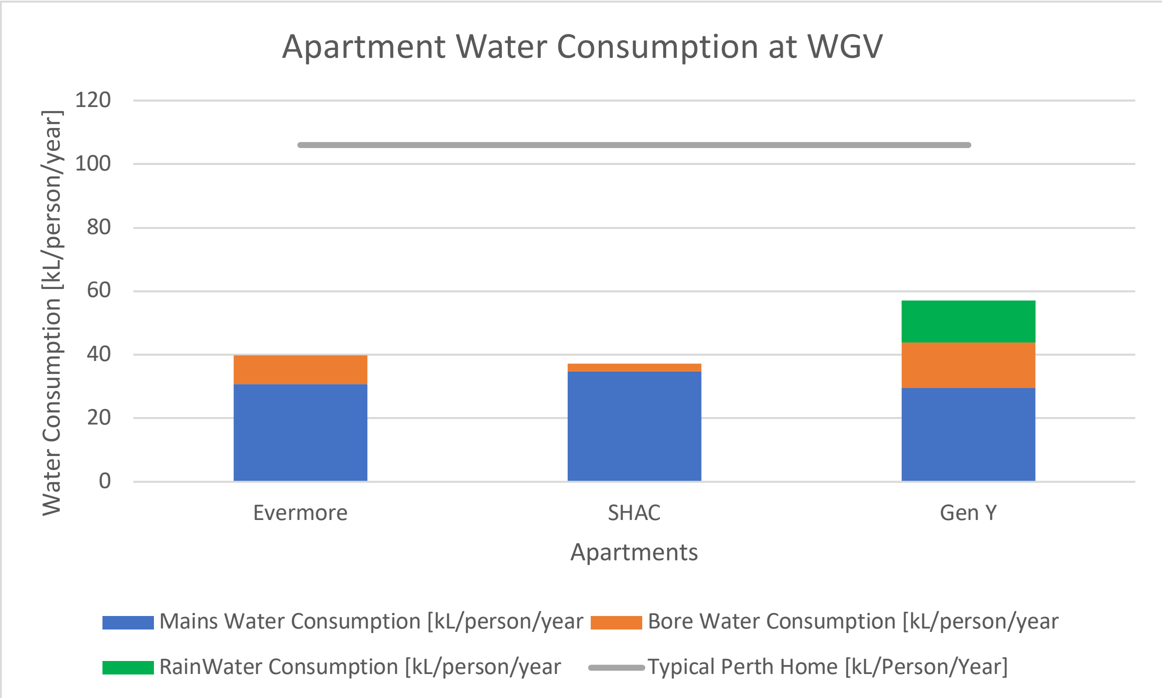

Figure 21. Apartment Water Consumption at WGV

The apartments were the closest typology to the modelled figure with a 32% difference between the performance data and the modelled figures. The mains water consumption was within 10% of the modelled figures, whilst the bore consumption difference was 12% when comparing to the modelled figures. Gen Y was the only apartment with the potential to record data for rain water consumption, with performance data demonstrating that Gen Y residents consume 13kL/person/year of rain water, which was a 30% increase in comparison to the modelled value.

5.2 Precinct Water Consumption

A precinct water balance of the performance data can be seen in Figure 22, which demonstrates the current precinct water consumption for mains, bore and rain water at WGV. Data has been collected for 46% of all water meters that are anticipated to be implemented at WGV upon completion of the precinct. This includes 57% of mains water meters, 43% of bore meters and 40% for rain water meters, hence why the numbers in Figure 22 are significantly lower than the preliminary modelling as seen in Figure 10. Comparing the modelled figures for the same amount of dwellings as the performance data provides the following results:

- The precinct mains water consumption is 49% higher than preliminary modelling.
- The precinct rain water consumption is approximately 22% higher than the preliminary modelling.
- Residential bore water consumption is within 10% of the preliminary modelling.
- Public open space irrigation is currently 4% higher than the preliminary modelling, this isn't expected to change as all POS have been established.

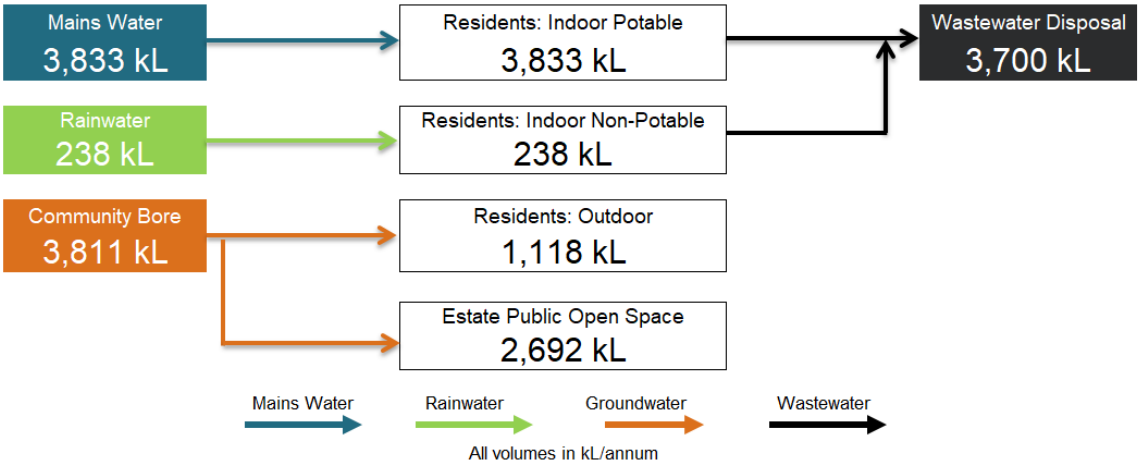

Figure 22. Precinct Water Balance from the Performance Data

According to Byrne (2016), for sustainable extraction to occur the direct on-site infiltration must be greater than the bore water extraction. In the WGV case, the on-site infiltration over the data collection period was approximately 9,600kL/year whilst the abstraction from the community bore was 3,811kL/year leading to the conclusion that the community bore at WGV is sustainably extracting bore water allowing the replenishment of the local aquifers.

5.3 Policy Implications

Following this study, a number of policy implications can be recognised including relevant organisations such as the Water Corporation and the Department of Water and Environmental Regulation (DWER) recognising that WGV has been a successful project at reducing both total water consumption and mains water consumption. From these results, the relevant organisation should strongly consider implementing these water reduction strategies into all policy to assure that all new developments in Western Australia implement the same or similar water reduction initiatives. Groundwater infiltration rates at WGV demonstrated that sustainable groundwater bore water consumption is achievable for precinct through the implementation of WSUD. It is recommended that the performance of WSUD practices for aquifer recharge is monitored to assure sustainable extraction. Other mains water reduction strategies that should be integrated into new policy includes the mandating of rainwater tanks, smart meters for leak detection, WELs efficient appliances, drip irrigation and low water use plants for verges.

5.4 Reflections and Lessons Learned

Through the completion of this Thesis a number of lessons have been learnt including:

- The mains water reduction strategies implemented at WGV have been successful at reducing mains water by 64% which is in line with the preliminary modelling completed by JBA.
- WGV provides a total water saving of 48% in comparison to typical Perth homes.
- The implementation of a community bore provides residents to meet their irrigation demand with non-potable water sources leading to a major reduction in greenhouse gases.
- Although Perth climates continues to dry, rain water tanks still have the capacity to provide an alternative water supply for appropriate demands.
- The successful infiltration of stormwater and sustainable extraction of bore water can be implemented and utilised for both public open space and residential irrigation demand.

5.4.1 Data Reliability

Through the data verification process explained in section 3.1.4 of this thesis, it can be understood that the data used to report the performance of WGV is reliable. Any data that was not validated or had inconsistency over the data verification period were not included in this thesis.

6 Conclusion

This report successfully quantified the performance of *WGV*, a sustainable precinct in Fremantle, Perth, Western Australia. A detailed analysis was completed for the precinct in regard to its average water consumption over various typologies. Over 62 smart meters were installed at the site on mains, bore and rainwater meters.

The data analysed, demonstrated that a typical WGV resident reduces its mains water consumption by 64% in comparison to the typical Perth metropolitan area, this is a result of the mains water reduction strategies deployed in the site including bore water (15kL/person/year), rainwater (7kL/person/year), water use efficiency and conservation. It was identified that Attached dwellings were the lowest water consumers in the precinct (28kL/person/year), followed by apartments (40kL/person/year) and then detached dwelling (89kL/person/year) with an overall precinct average of 55kL/person/year. This results in an overall water saving of 48% in comparison to typical Perth homes.

6.1 Study Aim and Objectives Addressed

The following conclusions on the aims of this study are:

1. ***Understanding the impact of the water reduction strategies at WGV in relations to mains water savings.***

The mains water reductions implemented at *WGV* achieved a 64% mains water saving in comparison to the typical Perth home whilst reducing total water consumption by 48%. It was recognised that the integration of a community bore and rain water tanks provides resident with an annual saving of 22kL/person/year (Bore Consumption: 15kL/person/year and Rain Water Consumption: 7kL/person/year).

2. ***Understanding the reasons for variations from the designed modelling.***

Overall the preliminary modelling predicted that mains water savings would range between 60-70% for residents in WGV, this was in line with the actual performance data that concluded a mains water savings of 64% in comparison to the typical Perth resident. Whilst there were some variations in the individual typology modelling, overall the modelled values were spot on, the comparison can be seen in Table 16. The two major variations that were recognised included:

- Residential irrigation continued during winter months leading to a 25% increase in bore water consumption for the precinct.
- Reduction in actual rainfall levels during the performance data period in comparison the preliminary modelling values.

Table 16. Comparison of Preliminary Modelled Data to Measured Performance Data across water sources

TYPOLOGIES	PRELIMINARY MODELLING (MAINS)	MEASURED PERFORMANCE DATA (MAINS)	PRELIMINARY MODELLING (BORE)	MEASURED PERFORMANCE DATA (BORE)	PRELIMINARY MODELLING (RAIN)	MEASURED PERFORMANCE DATA (RAIN)
DETACHED	30 kL/person/yr	52 kL/person/yr	12 kL/person/yr	29 kL/person/yr	10 kL/person/yr	8 kL/person/yr
ATTACHED	30 kL/person/yr	20 kL/person/yr	15 kL/person/yr	3 kL/person/yr	10 kL/person/yr	5 kL/person/yr
APARTMENTS	30 kL/person/yr	32 kL/person/yr	8 kL/person/yr	9 kL/person/yr	10 kL/person/yr	1 kL/person/yr
AVERAGE	30 kL/person/yr	38 kL/person/yr	12 kL/person/yr	15 kL/person/yr	10 kL/person/yr	7 kL/person/yr

3. ***Ascertain the sustainability of groundwater extraction at WGV in mind with the original design model.***

Currently, groundwater extraction at WGV is in line with the preliminary modelling, with both the residential irrigation and the public open space irrigation demand. Findings from this thesis demonstrate that the extraction rate is currently sustainable with on-site infiltration being greater than the groundwater extraction. It is recommended that further data collection continues to happen post this thesis as only 43% of bore meters have been validated and used in the data collection for this thesis. As more dwellings are completed and residential bores begin to irrigate the groundwater extraction rate is likely to change and therefore should be continuously monitored to assure all extraction is conducted sustainably.

6.2 Closing Summary and Further Opportunities

From these findings it is suggested that further studies are investigated to assess the compliance levels of the residents within *WGV*. This would incorporate grouping water consumptions levels with compliance levels according to the Design Guidelines provided by DevelopmentWA to better understand the large variations between residents and typologies at WGV. This would include a detailed analysis of the Design Guidelines as well as initiating on-site water audits and surveys to the residents. This study would determine whether the Design Guidelines have been the main reason for WGV to achieve their targeted water consumption and determine the passive savings associated with the water saving strategies that were implemented in the construction of the precinct.

Additionally, similar projects across various sites should be investigated to address the identified gap in the literature which demonstrated a limited number of water reduction residential development projects had completed performance data for comparison to their modelled values. This would provide developers with the opportunity to review a number of different water reduction strategies in various climatic zones to implement the most effective water saving initiatives into future developments.

Overall, the results showed that through the implementation of the mains water reduction strategies deployed at WGV, significant reduction in mains water consumption have been achieved, with reasonable alignment to the preliminary modelling.

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8 Appendix

8.1 Assumptions

Topic	*Figure*	*Unit*	*Comment*
Days in a year	365	Days/Year	
Excluded Data	Less than 150 days of data consumption	Days	All data has been excluded if data has not been received for over 150 days
	Greater than 10%	%	Any online data received that is not within 10% of the manual reads over the verification period has been excluded from this thesis
Rain Water	All data has been included		Rain Water meters were unable to be verified, therefore it was assumed the data was correct based on the verification of the mains and bore data
	705.5	mm/year	Rainfall over the data period was calculated at Swanbourne http://www.bom.gov.au/climate/dwo/201910/html/IDCJDW6121.201910.shtml
	NA	NA	Rainfall in the White Gum Valley is the same as the rainfall for Swanbourne
Roof Area	60	%	Assume 60% of Total dwelling area is roof
Groundwater Infiltration	40	%	Assumed
Precinct Water Balance	90	%	The Precinct water balance assumes that 90% of the incoming water is disposed of through wastewater disposal
Catchment Efficiency Coefficient	60	%	Assumed
Detached Occupancy	2.8	People / dwelling	Occupancy was assumed based on the ABS 2016 Data - https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/036
Attached Occupancy	5.6	People / dwelling	Occupancy was assumed based on the ABS 2016 Data - https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/036
Apartment Occupancy	1.8	People / dwelling	Occupancy was assumed based on the ABS 2016 Data - https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/036

8.2 Data Logger Installation Schematic

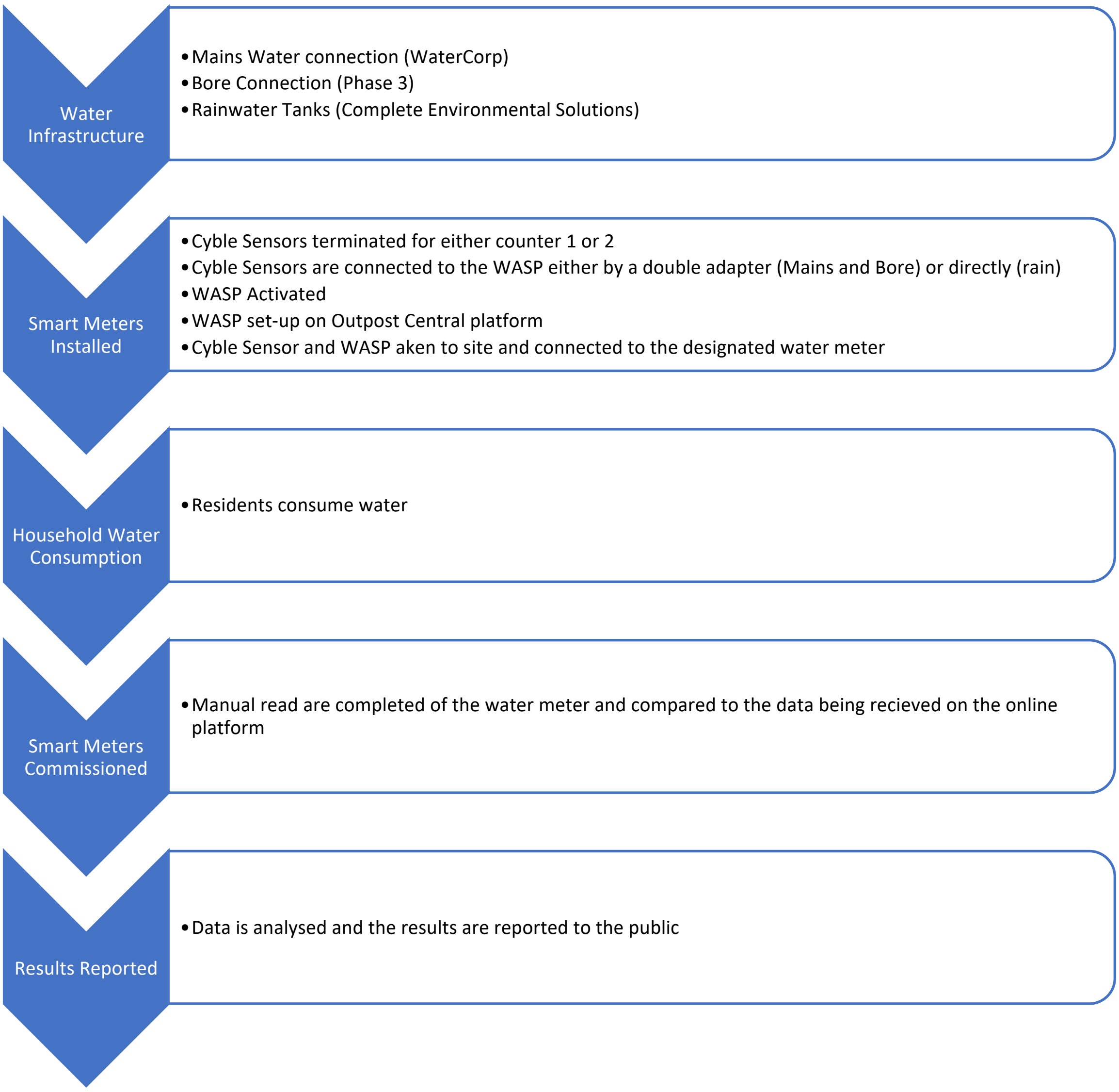
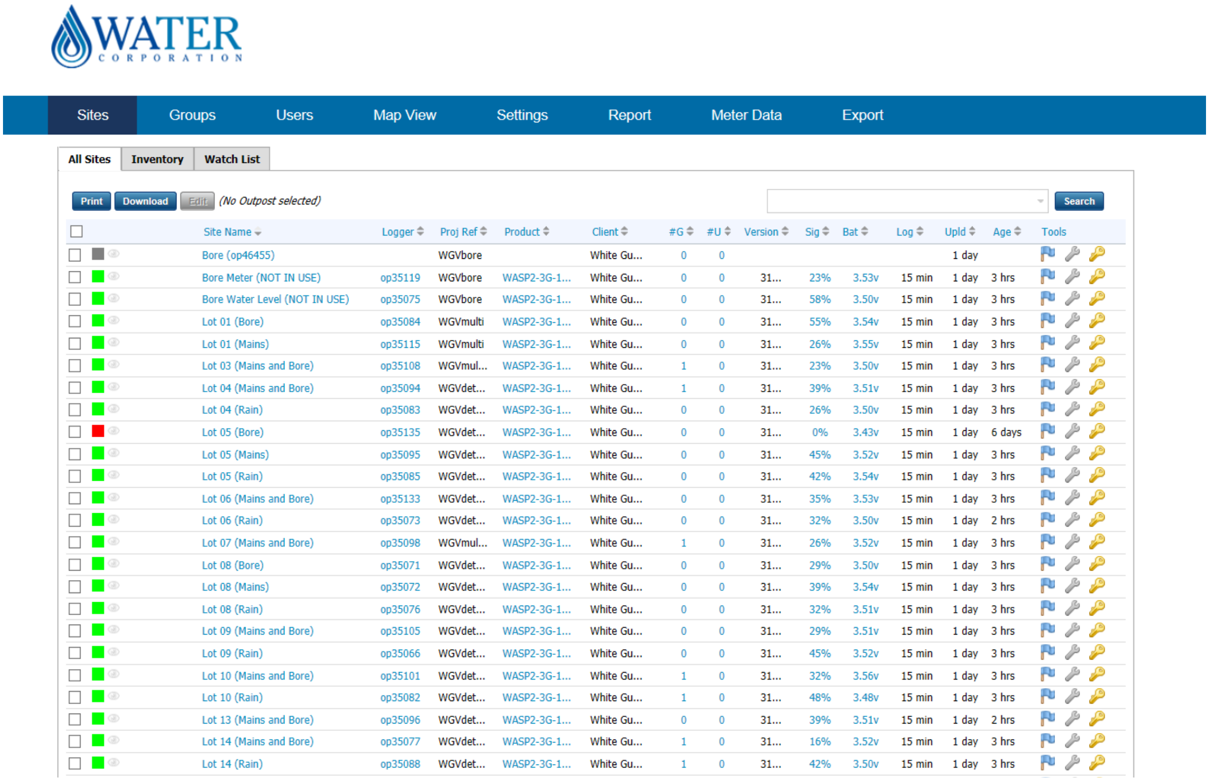


Figure 23. Flow Diagram of the Data Logging Installations

8.3 Overview of Outpost Central Platform



Site Name	Logger	Proj Ref	Product	Client	#G	#U	Version	Sig	Bat	Log	Upld	Age	Tools
Bore (op46455)		WGVbore		White Gu...	0	0					1 day		
Bore Meter (NOT IN USE)	op35119	WGVbore	WASP2-3G-1...	White Gu...	0	0	31...	23%	3.53v	15 min	1 day	3 hrs	
Bore Water Level (NOT IN USE)	op35075	WGVbore	WASP2-3G-1...	White Gu...	0	0	31...	58%	3.50v	15 min	1 day	3 hrs	
Lot 01 (Bore)	op35084	WGVmulti	WASP2-3G-1...	White Gu...	0	0	31...	55%	3.54v	15 min	1 day	3 hrs	
Lot 01 (Mains)	op35115	WGVmulti	WASP2-3G-1...	White Gu...	0	0	31...	26%	3.55v	15 min	1 day	3 hrs	
Lot 03 (Mains and Bore)	op35108	WGVmul...	WASP2-3G-1...	White Gu...	1	0	31...	23%	3.50v	15 min	1 day	3 hrs	
Lot 04 (Mains and Bore)	op35094	WGVdet...	WASP2-3G-1...	White Gu...	1	0	31...	39%	3.51v	15 min	1 day	3 hrs	
Lot 04 (Rain)	op35083	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	26%	3.50v	15 min	1 day	3 hrs	
Lot 05 (Bore)	op35135	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	0%	3.43v	15 min	1 day	6 days	
Lot 05 (Mains)	op35095	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	45%	3.52v	15 min	1 day	3 hrs	
Lot 05 (Rain)	op35085	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	42%	3.54v	15 min	1 day	3 hrs	
Lot 06 (Mains and Bore)	op35133	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	35%	3.53v	15 min	1 day	3 hrs	
Lot 06 (Rain)	op35073	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	32%	3.50v	15 min	1 day	2 hrs	
Lot 07 (Mains and Bore)	op35098	WGVmul...	WASP2-3G-1...	White Gu...	1	0	31...	26%	3.52v	15 min	1 day	3 hrs	
Lot 08 (Bore)	op35071	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	29%	3.50v	15 min	1 day	3 hrs	
Lot 08 (Mains)	op35072	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	39%	3.54v	15 min	1 day	3 hrs	
Lot 08 (Rain)	op35076	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	32%	3.51v	15 min	1 day	3 hrs	
Lot 09 (Mains and Bore)	op35105	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	29%	3.51v	15 min	1 day	3 hrs	
Lot 09 (Rain)	op35066	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	45%	3.52v	15 min	1 day	3 hrs	
Lot 10 (Mains and Bore)	op35101	WGVdet...	WASP2-3G-1...	White Gu...	1	0	31...	32%	3.56v	15 min	1 day	3 hrs	
Lot 10 (Rain)	op35082	WGVdet...	WASP2-3G-1...	White Gu...	1	0	31...	48%	3.48v	15 min	1 day	3 hrs	
Lot 13 (Mains and Bore)	op35096	WGVdet...	WASP2-3G-1...	White Gu...	0	0	31...	39%	3.51v	15 min	1 day	2 hrs	
Lot 14 (Mains and Bore)	op35077	WGVdet...	WASP2-3G-1...	White Gu...	1	0	31...	16%	3.52v	15 min	1 day	3 hrs	
Lot 14 (Rain)	op35088	WGVdet...	WASP2-3G-1...	White Gu...	1	0	31...	42%	3.50v	15 min	1 day	3 hrs	

Figure 24. Image of Outpost Central Home Page

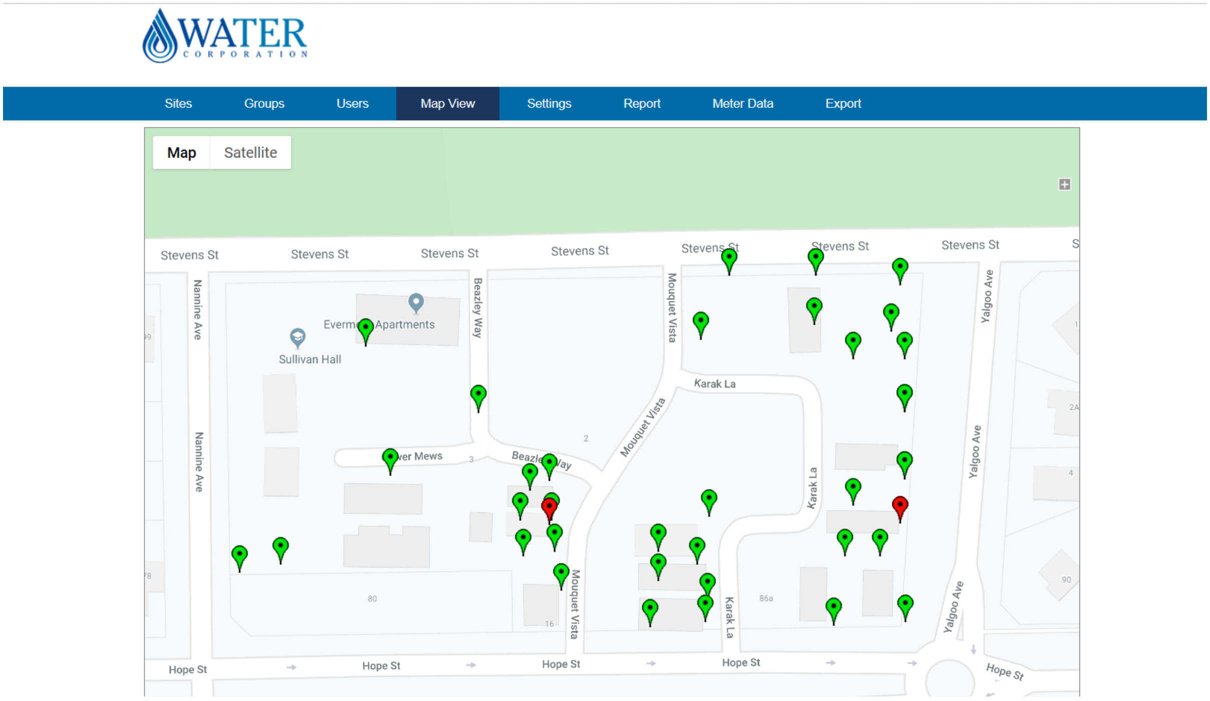


Figure 25.Image of Outpost Central Data Loggers Location

8.4 Data Loggers Verification

Lot	Typology	Meter Type	Initial Meter Read Date	Initial Reading (Manual)	Final Meter Read Date	Final Reading (Manual)	Manual Difference	Outpost Difference over the same period	% Difference
Detached 1	Detached	Mains	1/16/2019	177.7	7/30/2019	322.415	144.715	148.5	3%
		Bore	1/16/2019	139.7	3/18/2019	210.004	70.304	14.965	-79%
		Rain					0		
Detached 2	Detached	Mains	1/16/2019	233.18	7/30/2019	299.807	66.627	66.862	0%
		Bore	3/18/2019	44.25	7/30/2019	108.992	64.742	65.59	1%
		Rain					0		
Detached 3	Detached	Mains	2/4/2019	439.871	7/30/2019	532.834	92.963	93.76	1%
		Bore	3/18/2019	15.146	7/30/2019	26.137	10.991	10.995	0%
		Rain					0		
Detached 4	Detached	Mains	1/16/2019	187.83	7/30/2019	246.991	59.161	59.259	0%
		Bore	1/16/2019	77.67	7/30/2019	132.001	54.331	54.364	0%
		Rain					0		
Detached 5	Detached	Mains	1/16/2019	446.34	7/30/2019	560.907	114.567	116.137	1%
		Bore	1/16/2019	303.6	7/30/2019	359.366	55.766	59.139	6%
		Rain					0		
Detached 6	Detached	Mains	1/16/2019	172.43	7/30/2019	224.999	52.569	53.676	2%
		Bore	1/16/2019	126.202	7/30/2019	189.881	63.679	58.881	-8%
		Rain					0		
Detached 7	Detached	Mains	2/20/2019	154.975	7/30/2019	217.374	62.399	62.45	0%
		Bore	1/16/2019	0.027	7/30/2019	0.191	0.164	0.82	
		Rain					0		
Detached 8	Detached	Mains	5/20/2019	75.675	7/30/2019	108.08	32.405	32.98	2%
		Bore	1/16/2019	0.35	7/30/2019	0.036	-0.314		
		Rain					0		
Detached 9	Detached	Mains	1/16/2019	61.21	7/30/2019	107.881	46.671	47.269	1%
		Bore	1/16/2019	52.3	7/30/2019	131.925	79.625	79.637	0%
		Rain					0		
Detached 10	Detached	Mains	1/16/2019	128.549	7/18/2019	177.405	48.856	50.12	3%
		Bore	1/16/2019	80.82	7/18/2019	164.814	83.994	85.577	2%
		Rain					0		
Detached 11	Detached	Mains	4/5/2019	112.956	7/30/2019	155.519	42.563	43.407	2%
		Bore	4/5/2019	20.067	7/30/2019	29.822	9.755	10.069	3%
		Rain							
Attached 1	Attached	Mains	1/16/2019	118.607	7/30/2019	190.286	71.679	72.108	1%
		Bore	1/16/2019	85.042	7/30/2019	151.624	66.582	66.157	-1%
		Rain					0		
Apartment 1	Apartments	Mains	4/5/2019	877.07	7/30/2019	1207.6	330.53	333.4	1%
		Bore	1/16/2019	190.625	7/30/2019	361.933	171.308	171.446	0%
		Rain	NA	NA					
Apartment 2	Apartments	Mains	2/4/2019	1925.541	7/30/2019	2316.232	390.691	390.74	0%
		Bore	3/18/2019	108.25	7/30/2019	122.248	13.998	13.993	0%
		Rain	Balance Group	Balance Group	Balance Group	Balance Group	Balance Group	Balance Group	Balance Group
Apartment 3	Apartments	Mains	2/4/2019	353.036	7/30/2019	444.203	91.167	84.245	-8%
		Bore	1/16/2019	155.56	7/30/2019	212.596	57.036	56.415	-1%
		Rain					0		

Figure 26. Image of the Excel Spreadsheet used to validate the Online Data with the Manual Reads

8.5 WGV Estate Plan

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