Stochastic evaluation of per capita domestic water requirements in view of various lifestyles

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Declaration

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Abstract

Water authorities and policymakers are challenged with ensuring water supply for the future in the face of population growth, urbanisation and climate change. The possibility exists that water is being used at a rate that is much greater than is necessary for efficient daily use. It is important to determine daily water use requirements for different lifestyle habits. Other end-use studies have been conducted and household models have been created to evaluate household water use. However, per capita water requirements, for a range of lifestyles, have not been statistically modelled at an activity-based level. For this reason, a stochastic model entitled the litre per capita per day (LCD) model was set up to determine the domestic per capita water requirements for a single person, fully serviced, urban household at different lifestyle levels. The model was linked to Maslow's hierarchy of needs to define different water use categories. The lifestyle levels considered were the "absolute basic consumption" lifestyle level where only basic health and hygiene needs were met; the "realistic everyday acceptable limited consumption" lifestyle level which limits water use to indoor use, yet allows for the normal functioning of a household; the "esteemed needs" lifestyle level which allowed for indoor and limited outdoor water use and finally the "ultimate consumption" lifestyle level which allowed for unrestricted indoor and outdoor use. Probabilistic distributions were used to describe each model input. A Monte Carlo simulation was run using @Risk software to determine the expected distribution of water use for each lifestyle level. The model results showed that the average absolute basic water requirement to live a hygienic lifestyle is 92 L/c/d; the average realistic everyday acceptable limited consumption is 175 L/c/d, the average esteemed needs water use is 227 L/c/d and the average ultimate consumption is 314 L/c/d, in a fully serviced urban household. The model values were found to be comparable to consumption values found in literature. The results of this study can be used as guidelines for daily target values by water authorities and policymakers.

Uittreksel

Waterowerhede en beleidmakers word uitgedaag om die watervoorsiening vir die toekoms te verseker te midde van bevolkingsgroei, verstedeliking en klimaatsverandering. Die moontlikheid bestaan dat water gebruik word teen 'n veel groter hoeveelheid as wat nodig is vir doeltreffende daaglikse gebruik. Daarom is dit nodig om daaglikse watergebruiksvereistes vir verskillende leefstylgewoontes te bepaal. Ander eindgebruikstudies is uitgevoer en huishoudelike modelle is opgestel om huishoudelike watergebruik te evalueer. Waterbehoeftes per capita vir 'n verskeidenheid lewenstyle is egter nie op 'n aktiwiteitsgebaseerde vlak statisties gemodelleer nie. Om hierdie rede is 'n stogastiese model, geregtig op die litre per capita per day (LCD) model, opgestel om die huishoudelike behoeftes per huishoudelike per capita te bepaal vir 'n enkele, volwaardige, stedelike huishouding op verskillende lewenstylvlakke. Die model is gekoppel aan Maslow se hiërargie van behoeftes om verskillende kategorieë vir watergebruik te definieer. Die lewenstylvlakke wat oorweeg is, was die “absolute basiese verbruik” lewenstylvlak waar slegs aan die basiese gesondheids en higiënebehoeftes voldoen is; die “realistiese daaglikse aanvaarbare beperkte verbruik” lewenstyl wat die watergebruik tot binnenshuis beperk, maar tog die normale funksionering van 'n huishouding moontlik maak; die “gewaardeerde behoeftes” lewenstyl vlak wat voorsiening maak vir binnenshuise en beperkte watergebruik buite en uiteindelik die “uiteindelike verbruik” lewenstyl vlak wat onbeperkte binne en buite gebruik moontlik gemaak het. Waarskynlike verdelings is gebruik om elke modelinvoer te beskryf. 'n Monte Carlo-simulasie is uitgevoer met behulp van @Risk-sagteware om die verwagte verspreiding van watergebruik vir elke lewenstylvlak te bepaal. Die modelresultate toon dat die gemiddelde absolute basiese waterbehoefte om 'n higiëniese leefstyl te leef 92 L/c/d is; die gemiddelde realistiese daaglikse aanvaarbare beperkte verbruik is 175 L/c/d, die gemiddelde gewaardeerde behoeftes aan watergebruik is 227 L/c/d en die gemiddelde uiteindelike verbruik is 314 L/c/d, in 'n volwaardige stedelike huishouding. Die modelwaardes is vergelykbaar met verbruikswaardes in literatuur. Die resultate van hierdie studie kan gebruik word as riglyne vir daaglikse teikenwaardes deur waterowerhede en beleidmakers.

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Abbreviations, acronyms and symbols

AADD	annual average daily demand
CSIR	The Council for Scientific and Industrial Research
DHS	The Department of Human Settlement
D	duration
F	frequency
I	flow rate or intensity
LCD Model	Litre per capita per day model
L/c/d	litres per capita per day
L/hh/d	litres per household per day
PPH	people per household
SFWMD	South Florida Water Management District
WHO	World Health Organization

1 Introduction

1.1 Background

Humans have the right to "sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses" (United Nations Committee on Economic, Social and Cultural Right, 2003). A minimum quantity of water should be available for drinking, food preparation, bathing and sanitation. The most basic water requirement is stipulated by the World Health Organisation (WHO) and varies between 20 and 50 L/c/d (WHO, 2003). The basic water requirement determined by WHO is limited to access at an offsite tap and does not include houses with piped water. Considering only fully supplied households, an absolute basic consumption (ABC) value is defined in this research as the minimum household daily water requirement for a healthy, sanitary lifestyle. The ABC addresses the most basic human needs, as defined by Maslow's hierarchy of needs, being physiological and safety needs. However, it could be considered unjust to subject humans to a lifestyle where only the basic physiological needs are met. According to Maslow (1943), humans have different levels of needs, with self-actualisation being the pinnacle of human needs. Water consumers may have needs beyond physiological needs, such as mental health and a need for a sense of self-worth. This study considered various levels of needs, without getting involved in the ongoing debate about water being a commodity, or a human right which has been addressed by Johnson et al. (2016).

The human body is made up of approximately 70% water, which is needed for proper functioning, such as for digestion, lubrication of joints and heat regulation, to name a few examples (Forbes et al., 1956). Water is used within the body and lost through sweat, urination and defecation. The lost water, therefore, needs to be replaced; other liquids cannot be used directly to replace the water lost by the body. Water is also a universal solvent, for most solutes, which are also required to sustain the functioning of the human body (Pohorille and Pratt, 2012). Furthermore, water is needed for day to day activities such as cleaning of the body and washing clothes, dishes, et cetera.

Urbanisation has caused humans to live in closer proximity to one another than in earlier centuries, bringing about greater health risks. The health risks associated with urban living are closely related to diseases being spread more easily (Prasad, 2010). In order to help reduce the spread of disease and increase overall sanitation when living in an urban environment, increased cleaning of hands and the body may be required in comparison to what is required when living spaces are more sparse, as was the case in earlier non-urban cultures, or in current rural areas.

Given current technology, water is irreplaceable in everyday living and access to clean water is essential in modern society.

Water is a basic human need – without it people cannot survive. However, improved standards of living have been linked in earlier studies to increased water use (Dalhuisen et al., 2003), suggesting that high water use is a luxury to strive for. Residential, urban water consumption could be considered in terms of a hierarchy of needs. In 1943 Maslow derived a hierarchy of needs, describing the different levels of needs of a human being (Maslow, 1943). Five levels of needs were described going from the most basic human needs to all needs and desires being fulfilled. The five levels of needs from most basic to complete fulfilment are physiological needs, safety needs, belongingness and love needs, esteem needs and self-fulfilment needs (Maslow, 1943).

Physiological needs are the most basic human needs, which all humans have the right to. Physiological needs consist of food, water, warmth and rest. Safety needs are the need to be kept safe from the environment and any other dangers. Belongingness and love needs are the need to have friendships and intimate relationships and esteem needs include the feeling of accomplishment. Maslow believed that once the needs of one level have mostly been achieved, the needs of the next level are desired and strived for. Self-fulfilment needs, often referred to as self-actualisation, are the pinnacle of Maslow’s hierarchy, where full emotional, physical and creative abilities are met. Self-actualisation is described as the point at which all previous needs are sufficiently satisfied. Changes to the exact meaning of the hierarchy of needs have been made over time. Research has found that varying circumstance (Tang et al., 2002), type of society or cultural environment (Cianci and Gambrel, 2003) and age (Goebel and Brown, 1981), to name a few, influence the views of what constitutes each need.

Water use can be linked to the Maslow (1943) hierarchy of needs in that there is a basic water need for humans to survive. However, Maslow (1943) shows that humans desire to reach self-fulfilment. Therefore, it can be assumed that humans will have the same desire to achieve greatest level of satisfaction with regards to water use. There are a number of water uses that can be treated as basic human rights, such as water for drinking, cooking, flushable toilets and personal hygiene. However, some water uses could be considered luxuries and are not a necessity, such as irrigated gardens and swimming pools. A summary of the associated water uses, as used in this study, corresponding to the Maslow (1943) hierarchy of needs, is given in Table 1.1.

Table 1.1: The water uses associated with Maslow's hierarchy of needs

Maslow's Level	Indoor water use	Outdoor water use
1. Physiological Needs	Minimum water needs to be provided at a communal standpipe	No outdoor use
2. Safety Needs	The minimum amount of indoor water needed to live a healthy life	No outdoor use
3. Belongingness and Love Needs	Indoor water used to live a comfortable and healthy life	No outdoor use
4. Esteem Needs	Indoor water used to live a comfortable and healthy life, including watering of indoor pot plants	Minimum outdoor use - used for small gardens and restricted pool use and car/sports equipment washing
5. Self-fulfilment needs	Unrestricted indoor use for comfortable living and extra luxuries, such as indoor plants, large baths for relaxation et cetera.	Unrestricted outdoor use for luxuries, such as a landscaped garden with ponds, pool, hot tub, and car/sports equipment washing

1.2 Definitions

Definitions of some key terms used in this thesis are presented in this section. Some of the terms listed below have ambiguous definitions in different texts, or in different regions. The meanings presented below apply specifically to this research study.

1.2.1 Water consumption, water use and water demand

The Oxford Dictionary defines use as to "take or consume (an amount) from a limited supply" (OED, 2006), while consumption is defined both as "the action of using up a resource" and "the action of eating or drinking something" (OED, 2006). While use and consumption both define the act of taking from a resource, consumption has the added association of physically ingesting the resource. The term "water demand" is often used in literature (Blokker et al., 2010; Hoffman et al., 2006; Rathnayaka et al., 2017) and also in reference to the term "water demand management" (WDM). In this text, preference was given to the terms water use and water consumption.

1.2.2 Household water use

Household water use is defined in this study as any water that is extracted from any water resource for domestic use by a residential consumer. Water used in households for commercial purposes, such as running a small home business, was not considered household water use. This definition is notably different from the definition for a "water use" presented in the South African National Water Act (Republic of South Africa, 1998), where wastewater is also considered to be part of a water use activity. In this study, the term water use is independent of the source of water and exclusively relates to the individual using the water and the related point of use. The term water use in this study should be viewed relative to the individual consumer and is not linked to a water meter or a fixed property. The water use of an individual, thus, explains all the water needs of the particular individual, disregarding the spatial location, and also irrespective of the source of water. According to this definition, the application of, say, greywater reused inside the home to flush a toilet, would be viewed as a water use activity, added to the per capita consumption.

1.2.3 Water use activity

A "water use activity" is defined in this study as the specific activity for which water was used. Washing hands, brushing teeth, washing clothes and car washing are examples of water use activities. These activities include any indoor or outdoor activity in which domestic water was used. The supply of the water does not have to originate at the point of the activity. For example, a bucket of water can be drawn from the kitchen, shower or bath tap and used for washing the floors of the house. The water use activity, in this case, would be cleaning the house.

A water use activity differs from the commonly used "water end-use", also known as a "micro component", in that an end-use is the exit point (eg. tap) of the water from the distribution system, regardless of the activity for which the water is being used. Following the previous example, the end-use would be the kitchen, shower or bath tap, whereas the water use activity would be cleaning the house. Generally, an end-use is also a water use activity. Examples of water use activities that are, in all likelihood, end-uses include dishwasher, washing machine, shower and toilet. A water use activity is referred to as an "activity" in this study. A comprehensive list of all water use activities considered in this study is presented in Chapter 5.

1.2.4 Absolute basic consumption

The absolute basic consumption (ABC) is the minimum expected daily water requirement for an individual person, living in a fully serviced urban household, when subjected to severe water restrictions – typical for a temporary period (a few months) to endure a crisis. The ABC is limited to water that is considered essential for hygiene and physical well-being. The ABC aims to meet the first two needs - physiological and safety - of Maslow's (1943) hierarchy, as it relates to water use.

1.2.5 Realistic everyday acceptable limited consumption

The realistic everyday acceptable limited (REAL) consumption is defined as a relatively low level of consumption, allowing for a healthy, hygienic, sustainable life at a very basic lifestyle level, not meeting any of the higher-level human needs. The REAL consumption is considered in view of current technology and is the lowest level of consumption that could be sustained by a consumer indefinitely. REAL consumption meets the first three levels of Maslow's (1943) hierarchy of needs, with no compromise to community health, or personal hygiene.

1.2.6 Esteemed needs consumption

Esteemed needs consumption is water use that would be expected in a single-family detached house, with limited outdoor water use, as defined in more detail in this thesis. The same state of events could be linked, for example, to areas facing water restrictions. The imposed water restrictions are those of either permanent water restrictions as has been seen in California, Texas and Australia (Liu et al., 2019; Adapa, 2018) or early-stage water restrictions imposed during drought situations. As a result, a number of outdoor water use activities will have some restrictions placed on them, however, overall lifestyle satisfaction is met.

1.2.7 Ultimate consumption

Ultimate consumption is the daily water requirements, relating to the highest level of Maslow's (1943) hierarchy of needs. Ultimate consumption allows for luxuries such as irrigated gardens with exotic plants, a swimming pool and/or water feature while considering efficient use and no wastage. Ultimate consumption meets the self-fulfilment needs of Maslow's (1943) hierarchy.

1.3 Problem statement

Water use, typically, increases with an increased standard of living, which could be associated with human needs. The standard of living and water requirements of many consumers exceed the most basic needs, but the per capita water requirements for different levels of service, associated with different lifestyles and related needs, are not well understood and are thus dealt with in this study.

1.4 Motivation for the research

The detailed evaluation of per capita water use as presented in this thesis was initiated with the following motivation:

- Per capita water use is widely used in various countries for planning water services (see Troy and Holloway, 2004; Department of Human Settlement, 2019; Hussien et al., 2016) and is also useful as the most basic, uncomplicated method for estimating water use since only one input parameter is required;
- Consumers and policymakers require a better understanding of target daily water use, suggesting a need for an investigation into realistic target water use values;
- There is a lack of theoretically based water use guidelines describing the needs of communities making it difficult for authorities to plan for future water use and related infrastructure; and
- The idea of implementing daily water use restrictions has been brought up by water authorities around the world; but limiting per capita values have not been extensively studied resulting in a need for water use values, for varying lifestyle levels, to be determined.

1.5 Research methodology

This study used a quantitative approach, which involved collecting and analysing statistical water use data, sourced from the available literature. Survey research, by means of an online questionnaire, was conducted in addition to the collection of data from literature to verify or build on pre-existing data. A stochastic model, namely the litre per capita per day (LCD) model, was developed using the collected data to evaluate the per capita water requirements of various lifestyles. Due to the uncertainty surrounding water use activities (eg. different shower durations), a stochastic approach was required rather than a deterministic approach.

1.6 Aims and objectives

The following objectives were identified for this study:

- Conduct a comprehensive review of all literature covering the following: minimum water requirements to survive, current domestic water use, water use activities and water requirements for different water use activities;

- Classify specific lifestyles to be associated with each level on Maslow's (1943) hierarchy of needs;
- Define water use needs, linking to indoor and outdoor water use, for each lifestyle level previously identified;
- Identify and group the water use activities required to fulfil the water use needs defined in the previous step;
- Design a per capita water use model framework and identify all related model input parameters, describing the water use activities from the previous step;
- Obtain statistical distributions of water use for each model input parameter and identify uncertain water use parameters;
- Set up an online questionnaire to gain insight into the uncertain water use parameters;
- Develop a stochastic model, using @Risk software, that considers the distribution of water use for each water use activity;
- Determine the expected water use for each selected lifestyle level for a single-person household by performing a 100 000 iteration Monte Carlo simulation on the stochastic model; and
- Compare results to available publications for the selected lifestyle levels, where previous publications are available.

1.7 Scope and limitations

1.7.1 Domestic water use

For this study, the scope of water use was limited to domestic water use. All non-domestic water uses such as for business, commercial and industrial use (ICI), sports fields, parks and shopping centres were not considered. The reason for excluding the aforementioned categories is because research into agricultural water use (Department of Human Settlement, 2019), as well as water use for tourism and other non-domestic activities (Kriegler and Jacobs, 2000; Blokker et al., 2011; Gossling et al., 2012) has previously been studied. This study included water used only for domestic purposes both in and around the home as well as water used outside of the physical home space. Therefore, should a person shower, say, at the gym or use the toilet at work this water is allocated to the per capita consumption.

1.7.2 Regional scope and level of supply

The study focused on houses that are equipped with regular water use appliances such as toilets, washing machines and dishwashers. Alternative sanitation practices such as using pit toilets or communal baths were not considered as part of this study. Furthermore, this study considered household water use in a developed area, with a constant water supply to multiple taps in a household, meeting all hygiene needs.

1.7.3 Single-person household

Research has found that the per capita water use decreases as the number of occupants in a household increases (Cavanagh et al., 2002; Höglund, 1999; Morgan, 1973). Therefore, in order to remain conservative and evaluate the maximum per capita water requirements, a single-person household was primarily considered.

1.7.4 Exclusion of basic water needs

Thorough research has been conducted into the absolute basic water needed to survive. It has been concluded that a person can survive off 20 to 50 L/c/d (Gleick, 1996; WHO, 2003). However, the range has been determined for areas where access to water is generally limited to a standpipe, either on-site or within walking distance of the home. Since the quantity required for basic water needs is well defined and does not fall within the scope of optimal access, the absolute basic water needed for survival was not modelled as part of this study.

1.7.5 Exclusion of wasteful and inefficient water use

Water used for various water use activities may exceed the values suggested in this study, generally for one of the following reasons: leakages are common in any household, especially those with older water use appliances – further discussion on leakage can be found in section 5.4.2; inefficient appliances may be present, which are not cost-effective to replace or retrofit and some members of the population do not use water mindfully, either due to ignorance or indifference, which leads to unnecessary wastage. Therefore, some limited allowance was made for leakage, water loss and inefficient water use. Earlier research has found leakage of between 10% and 20% (Heinrich, 2009; Water Corporation, 2010). Exclusion of all water losses from the model was therefore deemed to be unrealistic.

1.7.6 Assumptions related to selection of model input parameter values

Since the model developed in this study has 135 model input parameters, it was not always possible to find literature values for each parameter. Therefore, assumptions were required for a number of input values and/or parameter distributions. Where no literature values were available, the parameter distributions were limited to lognormal, uniform and triangular when a continuous parameter was appropriate and a Poisson or binomial distribution when a discrete parameter was appropriate. When modelling continuous variables, where literature suggested an equal chance of any volume within a range being used, a uniform distribution was used; when a single water use value was most likely to occur with less prominent high and low values occurring, a triangular distribution was used; all other assumed continuous distributions followed a lognormal distribution. When modelling discrete variables, a binomial distribution was used to determine the occurrence of a water use activity and a Poisson distribution was used when the frequency of occurrence was required.

2 Literature Review

2.1 Domestic water use

2.1.1 The need for water

Water is required for many everyday activities, some of which are crucial to human survival. Water is required for consumption, directly for drinking and indirectly for cooking. Furthermore, water is required for hygiene purposes such as for washing hands, food preparation, showering or bathing. A lack of clean water often leads to a lack of hygiene which can lead to diseases such as diarrhoea or other faecal-oral diseases, typhoid and skin and eye diseases (Bradley, 1997). Esrey et al. (1985) determined that the quantity of water has a greater effect on the reducing the frequency of diarrhoea events than the quality of the water.

Van Zyl et al. (2008) define domestic water as water that is used for any household activity, both indoor and outdoor; including water for drinking, cooking, laundry, cleaning, flushing toilets, garden use, pool use, pet care, car cleaning et cetera. Thompson et al. (2001) specifies four categories of domestic water use, namely: hygiene (including personal and household cleaning), consumption (including drinking and food preparation), amenity use (including car washing and garden and lawn irrigation) and productive use (including water for livestock, small-scale horticulture and other household productions). The latter applies more to water use in less developed countries where many people sustain themselves by cultivating backyard crops and keeping livestock, or by having small bartering or trading businesses from home.

Several water requirements are essential for living, with regards to health and hygiene. Conversely, other water use may not be vital to health and hygiene but, may be considered necessary for maintaining a relatively higher standard of living; these include irrigation and water for car washing or pools. Willis et al. (2011) referred to the two main types of water uses as non-discretionary and discretionary end-uses, respectively. In recent years the line between non-discretionary and discretionary water use has become blurred as people tend to use non-discretionary end-uses as discretionary end-uses. For example, a shower which is typically a non-discretionary end-use, with the purpose of cleaning the body for hygiene purposes, has become a discretionary end-use as people no longer use showers simply for sanitation but rather as a leisure activity. Thus, Willis et al. (2011) argue that there should be a set amount of water of approximately 40 to 70 L/c/d, that is a set requirement for basic human needs. This water allocation is defined as non-discretionary water use and any water use above this value should be considered discretionary water use, irrespective of what it is being used for. Water loss and leakage is common in residential homes. Leakages are neither non-discretionary nor discretionary as they are not influenced by behaviour.

2.1.2 Per capita water use

Per capita water use can only be determined accurately if the number of occupants in the household is known. Once the household size (people per household) is known, the daily household water use can be divided by the number of occupants to determine the per capita water use. Logically, not all members of the household will use the exact same amount of water as each member will have varying water use habits. However, this method provides a fairly accurate average per capita water use for a household and is commonly employed in research studies (Domene and Saurí, 2006; Dias et al., 2018). A summary of earlier studies that reported per capita water use, many of which used the aforementioned method to determine per capita water use, is provided in Appendix A.

2.1.3 Notable studies into water end uses and activities

A number of notable international studies were used in the development of the LCD model. A study was deemed notable if information regarding water use and/or water use distributions for multiple water use activities was presented in the study. The most notable studies are Roberts (2005), Blokker et al. (2010), Hussien et al. (2016) and Gleick (2003). Other less notable studies include Richter (2010), Richter (2011), Hand et al. (2005), Rosenberg (2007) and Vinogradova et al. (2012). Some notable South African studies include Jacobs and Haarhoff (2004a), Van Zyl et al. (2008), Du Plessis (2007) and Jacobs (2007).

The Yarra Valley residential end use study conducted by Roberts (2005) placed high resolution water meters into 100 Yarra Valley homes. The water meters took readings every five seconds for a two week period in both winter and summer. Water end uses were disaggregated from the water meter readings using Trace Wizard. Results from surveys conducted at the measured households were used to compare to the measured water use data. Trace Wizard cannot always distinguish between events with similar characteristics, which could lead to events being mischaracterised. However, the technology allows for disaggregation accurate enough for the purpose of determining average water use for different water end uses.

Blokker et al. (2010) developed a stochastic end use model to determine water use patterns at a residential level for a one second time scale. Statistical parameters found for frequency, flow rate and duration as well as the penetration rate (percentage of the target market reached with a product) of different water end uses, based on census data, were used in the development of the model. Measured data were compared to the simulated results of the model, which were found to be comparable.

Hussien et al. (2016) conducted a survey of 407 households in Duhok City, Iraqi Kurdistan to help determine water use patterns of developing countries. The survey consisted of 40 questions which covered household characteristics such as household size, number of adults and children and garden area; as well as questions pertaining to water end use behaviours. The results provided insight into household water use in low, medium and high-income households in Duhok. Furthermore, information about the characteristics of different end uses was gathered. Per capita water use of 241, 272 and 290 L/c/d was determined for low, medium and high-income houses. Following data collection, a statistical model was developed, which allowed for future demand to be modelled.

Gleick et al. (2003) provided insight into the possible effects of implementing water reducing measures into a Californian household. The study investigated both water saving technologies and policies available at the time. The conservation technologies investigated included low-flow toilets; flow reducing taps and showerheads; efficient residential dishwashers and washing machines; and drip and precision irrigation sprinklers. The conservation policies investigated included water pricing schemes; subsidy, rebate and financial incentive programmes; implementation of new state and national efficiency standards for appliances; education and public awareness programmes and water metering programmes. The results showed that a 30% reduction in water use could be achieved from California's 2000 water use.

In order to get a general idea of how much water a household should be using, guidelines set out by the department of water affairs and the DHS can be consulted. DWA (2009) provides guidelines for per capita water use for different settlement categories. With values ranging from 60 to 150 L/c/d for rural and farm villages and 200 to 250 L/c/d for permanent residents in coastal towns or small towns with water needs for animals and small gardens. The DWA (2009) makes provision for coastal towns that have seasonal visitors with a per capita water requirement of 80 to 130 L/c/d due to the seasonal nature of the residents. The DHS's (2019) published expected per capita water use ranges were provided for different dwelling types, with typical expected water use ranging from 60 L/c/d for a low income house to 400 L/c/d for a residential household.

Van Zyl et al. (2008) found that the guidelines published by the CSIR (2005), prior to their revision in 2019 (Department of Human Settlement, 2019), only accounted for 53% of suburbs and so a study was conducted to determine new guidelines for AADD. The study database comprised of almost 1.1 million consumption records ranging over 48 municipalities, located in 5 of the 7 water regions in South Africa. A process of determining the best method to set up the proposed AADD guidelines was conducted so that a variety of factors such as stand size, stand value and location, which were seen to have a significant effect on water use, could be considered. The proposed guidelines take only stand area into account and give different confidence intervals in which a given percentage of AADD would lie. When considering the current water use in South Africa, these guidelines give a more accurate estimation of the water use of a household based on its stand size.

Du Plessis (2007) conducted a study in which the overall water usage of 57 towns or communities in nine different municipalities within the Western Cape was investigated. The investigation used the bulk water usage, after treatment, divided by the population size of the communities to provide the daily per capita water use for each community. Using the bulk water usage for these towns gives a fair indication of the overall water required for everyday living, however, it includes both domestic and non-domestic water use, such as water for businesses and schools et cetera. Most of these communities do not have much farming within the town and any surrounding farms, generally, are self-sustaining and thus do not use municipal water. Therefore, all the water used is for every-day activities for the local people and not for agricultural purposes. The study found 10 communities which had either unexplainably high or very low water use; removing these communities, the average water use was 201 L/c/d, with about 15% being non-revenue water.

Jacobs (2007) conducted a study that investigated the water usage of high-density, low-income (HDLI) households within the Western Cape. Since most HDLI properties do not contain garden areas, the water use from these households is considered to represent indoor water use. The study, which was conducted with 113 respondents, found a range of 66 to 156 L/c/d depending on the household size (varying from 5 to 2 people per household, respectively).

2.2 Minimum water use

The World Health Organisation (2003) conducted a study to determine the minimum amount of water needed to meet basic health-related needs. The study determined the water requirement for food preparation, hydration and for basic hygiene. The study found that people who had to collect water from a communal facility used on average 20 L/c/d, while those who had a single tap at their dwelling used on average 50 L/c/d. However, for the case where multiple taps are available in a household, a value of greater than 100 L/c/d was determined.

Gleick (1996) set out to determine an absolute minimum water requirement that should be provided to all human beings in order to meet their basic human needs. A minimum value of

50 L/c/d was recommended, with 5 L/c/d for drinking water, 20 L/c/d for sanitation, 15 L/c/d for bathing and 10 L/c/d for cooking and kitchen. It was noted that different water use is expected for different levels of service as well as different climatic conditions, with higher water use expected for dry regions and fully connected houses with gardens.

The amount of water needed for human health as well as social and economic development of a country was researched by Chenoweth (2007). The water requirements considered both domestic as well as commercial water use, however, agricultural water was excluded. The minimum water requirement for development was determined, firstly, by investigating the water use by developed countries, allowing for the interconnected nature of industries to be taken into consideration, and later verified by using a first principles approach. The first principles approach included investigating the hypothetical minimum water requirements for each economic sector. A minimum water requirement for social and economic development was determined to be 135 L/c/d. 10 to 15 L/c/d of this water is attributed to a ±10% water loss in the system and the remaining 120 L/c/d is for domestic and commercial use. Chenoweth (2007) noted that even though it may be theoretically feasible to meet domestic and commercial development needs with a water use of 135 L/c/d, of all the developed countries at the time, only the United Arab Emirates and Kuwait have water use less than 135 L/c/d, while most 'low water use' countries reported water use values of between 270 and 430 L/c/d.

The international space station could be considered to represent the lowest water use possible, given current technology. Water use of a mere 1 L/c/d for crew and 0.45 L/d for payloads is maintained aboard the space station (Tobias et al., 2011). Such a low water use value is possible through an almost closed loop system of recycling and producing water. Water is recycled from urine and condensation from sweat and other sources of evaporated water by collecting and treating all moisture and returning the fluid to a potable state. In a separate closed system, water is used to produce oxygen and hydrogen. The remaining hydrogen is then combined with CO_2 to produce water and methane gas. A summary of the water inputs and outputs for a single crew member per day is given in Figure 2.1.

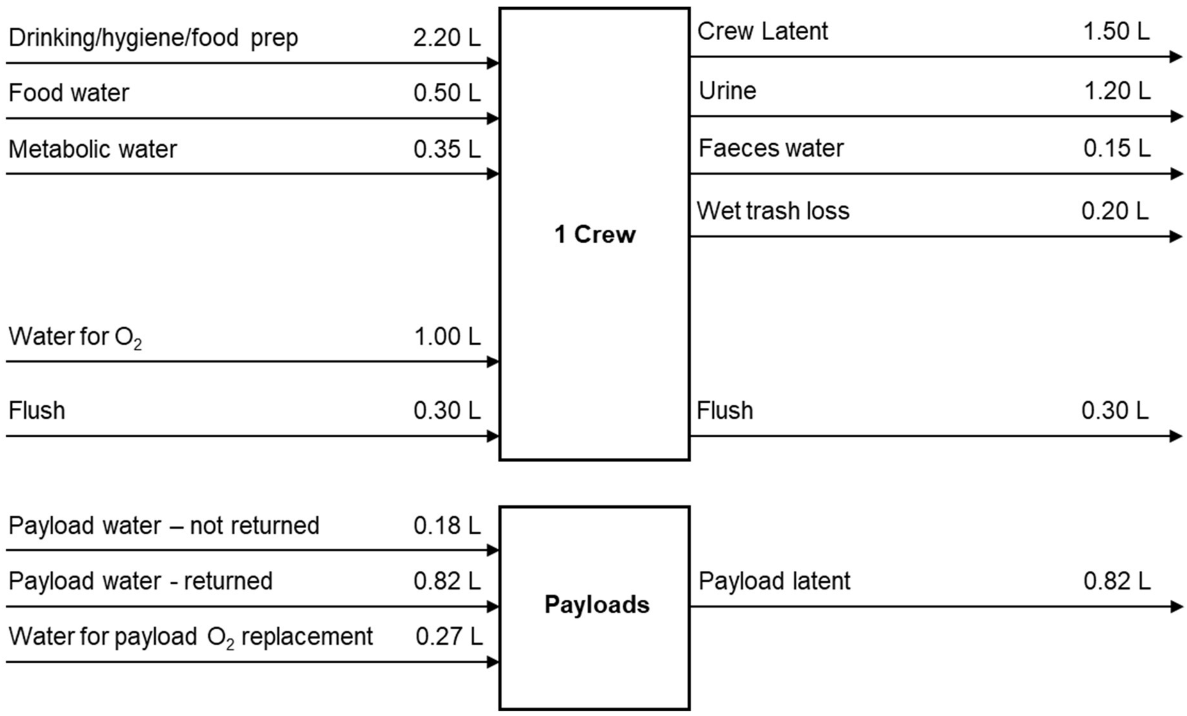

Figure 2.1: Water inputs and outputs of the space station (Tobias et al., 2011)

2.3 Household size

Household size varies notably and contributes significantly to domestic water use, having been found to be the most significant factor affecting household water use (Rathnayaka et al., 2014). As household size increases, the water use of the household increases due to the increased occupants in the household each requiring water. Conversely, the per capita water use of a household decreases as the household size increases. The decrease in per capita water use is due to many household water uses, such as washing machines, dishwashers, cooking and irrigation, being shared amongst the occupants of the household. Domestic water use is also affected by the age and occupation of the members of a household. The age of the occupants in the household has an effect on water use as the activities of individuals changes with age and the associated lifestyle (Browne et al., 2014). When showers are used, children and teens have been found to shower for longer than adults, thus increasing household water use (Mayer et al., 1999). In Germany, household water use has also been found to increase with age, often because the elderly who are retired spend more time in the house, which implies an increased likelihood to use water (Schleich and Hillenbrand, 2009).

Attempts have been made to study and model the effect of an increase in household size on per capita water use. Schleich and Hillenbrand (2009) determined in a study in Germany that with a 50% increase in the average number of household occupants, per capita water use decreased by 22%. Cavanagh et al. (2002) found comparable results, while Höglund (1999) found in a Swedish study that the per capita water use decreases as much as 27% to 35%, with a 50% increase in household size. Jacobs (2004) determined an equation to model the decrease in per capita water use (L/c/d) with an increase in household size (people per household), based on studies by Edwards and Martin (1995) and Morgan (1973).

A number of international empirical studies have been conducted that have measured water use for households of varying size (Arbués et al., 2010; Lee et al., 2012; Sadr et al., 2016; Koketso and Emmanuel, 2017; Smith, 2010). DeOreo and Mayer (2012) compiled a review of five different end-use studies conducted in North America, specifically, REUWS (Mayer et al., 1999), USEPA combined retrofit report (Aquacraft, 2005), CSFWUES (DeOreo et al., 2011), NSFHS which was split into the standard new home group (SNHG) and the high efficacy new home (HENH) group (DeOreo, 2011). A graphical representation of the decrease in per capita water use with an increase in the household for each study is shown in Figure 2.2.

Typical household size for western countries generally ranges between 2 and 3 PPH (House-Peters et al., 2010; Rathnayaka et al., 2017), while the household size in urban areas in less developed countries ranges between 2 and 5 PPH (Jacobs and Haarhoff, 2004a). Townships or communal living areas in less developed countries have household sizes ranging between 5 and 10 PPH (Emenike et al., 2017; Jacobs and Haarhoff, 2004a; Mazvimavi and Mmopelwa, 2006). Caution should be taken with studies conducted in countries that have a mix of townships and urban areas, as data on the household size might be skewed by studies that include both development types.

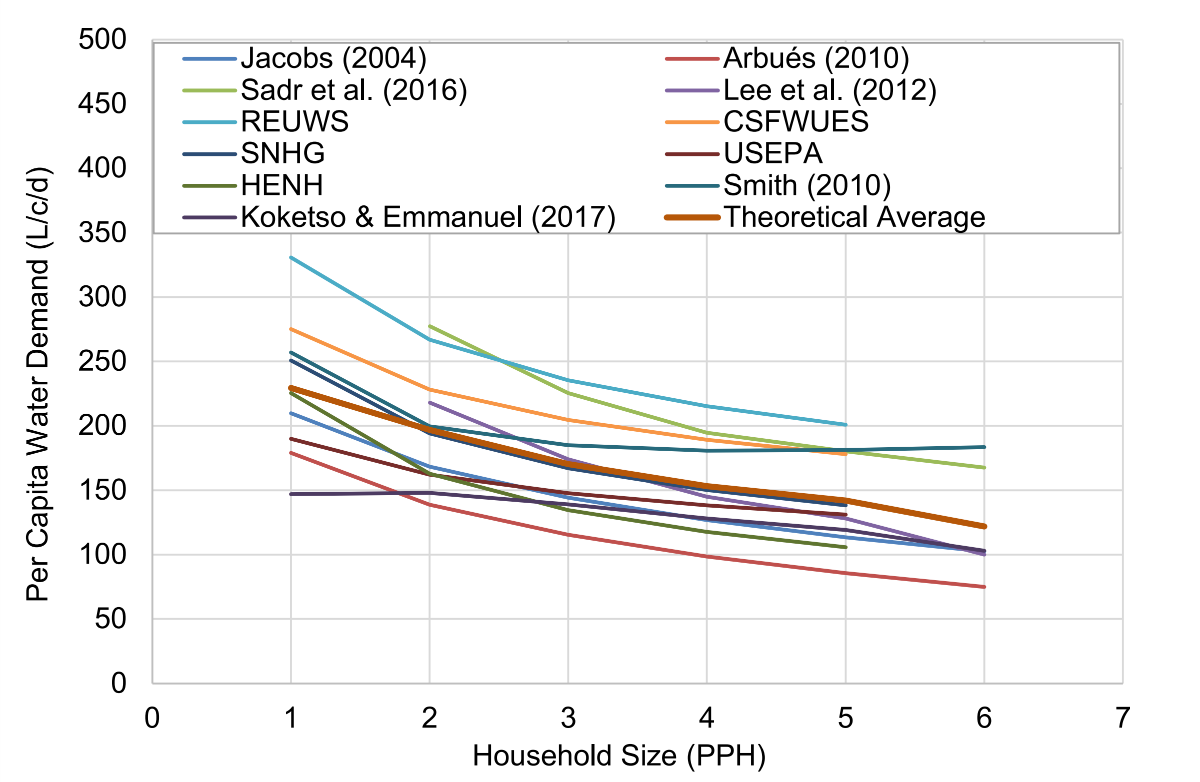

Figure 2.2: Summary of studies showing the effect of PPH on per capita water use

2.4 Household income

Studies show that there is a correlation between household income and water use (Ferrara, 2008; Van Zyl et al., 2008; Beal and Stewart, 2011). The increase in water use with increased household income may be due to larger landscaped gardens that require more water, more water intensive appliances being present in the household and smaller regard for the price of water.

2.5 Geography and climate

The location of a household affects the water use as the climate, terrain, nature of the activities performed in the area all affect the water use habits of the occupants of a household.

Climate and temperature have been found to affect water use. Topology and the presence of an irrigated garden and a swimming pool have the greatest impact on water use in summer, while household size and appliance efficiency have the greatest impact on water use in winter (Rathnayaka et al., 2014). The effect of temperature and rainfall on water use is more significant in areas that have warmer climates. The effect of warmer climates is most prominent in households with large gardens and swimming pools as their outdoor use, which is often weather dependent, is higher (Jorgensen et al., 2009). An increase in rainfall in a season has also been found to decrease water use as there is usually a reduction in outdoor water use (Rathnayaka et al., 2014). The reduction in water use due to the occurrence of rainfall is more psychological. The mere occurrence of rain and not necessarily the quantity of rain often reduces outdoor water use (Martinez-Espiñeira, 2002). However, there is a threshold beyond which rainfall as well as temperature no longer have a significant effect on water use. There has, however, been minimal investigation into a rainfall and temperature threshold for different regions (Arbués et al., 2003).

Holiday homes are used periodically, either by the owner or by tourists who occupy the home temporarily. The water use for these houses varies by season, with water use during peak season being found to be higher than residential areas without holiday homes (Hadjikakou et al., 2013). Therefore, water use in areas with a high population of holiday homes is not a true indication of residential water use.

2.6 Level of service

Asefa et al. (2015) define the level of service as “an informal contract between a utility and its customers for a certain degree of inconvenience”. In other words, the level of service with regards to water is the ease of access to water, provided by water utilities. The World Health Organisation splits the levels of service into four categories: (i) no access, (ii) basic access, (iii) intermediate access and (iv) optimal access. The levels of service are defined by the travel distance or time to the access point of clean water, or by the number of access points at a house for the higher levels of service (WHO, 2003). Furthermore, the level of service dictates the typical water consumption for a household.

The DHS (2019) split the levels of service into access from a standpipe, yard connections and house connection for low-income housing, cluster homes, flats and residential houses. The expected water use is based on the development level of the dwelling.

2.7 Age of the house

The age of a house, since initial construction, effects the water use of the household. It has been found that older houses have higher water use. Older houses are more likely to have older appliances, which generally means the appliances are less efficient. Older homes are also more prone to leaks in the plumbing system, resulting in a higher water use (Guhathakurta and Gober, 2007; Nauges and Thomas, 2000). However, it has been found that houses built before the 1970s are more water efficient than houses built between 1970 and 2000, as the water use appliances have mostly required replacing and have thus been replaced with more water efficient water appliances (Mayer et al., 1999). Contradictory data have been found showing higher water use in more modern households due to a higher presence of water use appliances and irrigation systems (Mayer et al., 2000; Rathnayaka et al., 2014). Therefore, water usage cannot easily be related to the age of a house. Rather the age of appliances, the presence of new water intensive appliances and the presence of new water efficient appliances, which often are related to the age of a house, need to be considered.

2.8 Previously developed models of domestic water use

2.8.1 Trace Wizard

Trace Wizard technology was developed by Aquacraft to differentiate between end-uses, as used by Meyer and DeOreo (1999) and Roberts (2005). Trace Wizard devices use end-use flow characteristic identifiers to determine the likely end-use that is being used at a specific time, allowing for disaggregation of events. Trace wizard can determine characteristics such as start time, stop time, duration, volume, mode frequency, peak flow rate and mode flow rate for each event. However, some end-use characteristics, such as different tap uses, are similar or may be overlapped with other events which results in missed end-uses or misidentification of end-uses.

Another method to identify end-uses is to attach metering devices to each end-use device which will allow for the identification of specific end-uses. The problem still arises with identifying water use activities that originate from one end-use, as the specific water use activity cannot be disaggregated from grouped end-uses. For example, a car wash event cannot be disaggregated from a garden irrigation event if the same outside tap is used for the event.

2.8.2 REUM

A first of its kind residential end-use model (REUM) was developed by Jacobs (2004). The model estimated five different components of residential water demand and return flow for 16 different end-uses. The five components were indoor water demand, outdoor water demand, hot water demand, wastewater flow volume and wastewater solute concentration. The model requires inputs for a total of 111 parameters, including four parameters for indoor demand, five parameters for outdoor demand, three parameters for hot water demand and one parameter for wastewater flow volume and wastewater solute concentration. The inputs for these parameters are best estimated by physical measuring but are sometimes estimated through subjective evaluation based on prior knowledge or consumer estimation. The application of REUM can be seen in a study by Jacobs and Haarhoff (2004a).

2.8.3 SWIFT

SWIFT is a South African based software, developed by GLS consulting engineers (GLS Consulting, 2019), that was developed to assist infrastructure managers in the effective management of South African water infrastructure. The software accesses the municipal treasury database providing information regarding the address, zoning, owner, value of the stand as well as the meter number and readings for individual stands. A detailed report of the development and implementation of the SWIFT software is provided by Jacobs and Fair (2012). SWIFT software gives the household consumption per stand which can only be translated to per capita consumption should the household size be known.

2.8.4 SIMDEUM

Blokker et al. (2010) developed a model which statistically describes end-uses in order to model diurnal water use patterns. The model set up is based on the premise that water use occurs as a non-homogeneous rectangular pulse as is shown by Buchberger and Wu (1995). However, various probability distributions were used for flow rate, duration and the arrival time of the pulses for each end-use. The distributions were populated using survey data rather than measured data. The time of water use, frequency and duration was considered by categorising households by household size, their occupant's age and gender. A time budget survey was used to link the characteristics of the household occupants to times at home.

The model considered eight end-uses, namely, kitchen tap, bathroom tap, bath, toilet shower, dishwasher, washing machine and outside tap; with each end-use being assigned a penetration rate. The penetration rate for most appliances in the Netherlands is 100%, however, including that parameter allows for the model to be adapted to other study locations Blokker et al. (2010).

Once all parameters are modelled a Monte Carlo simulation can be run to provide a distribution of water use values, ultimately giving an average water use for the household. The model was tested against measured values showing a strong agreement at different time and spatial scales Blokker et al. (2010).

3 Approach to Model Development

3.1 Initial development

Modelling water use has an element of uncertainty due to variability in many of the model parameters. A deterministic approach can be followed when modelling water use by using the mean or the worst-case value for each parameter input. However, it is emphasised by Loucks and Van Beek (2017) that when important parameters are highly variable, performing a deterministic analysis can produce inaccurate results. Due to the number of uncertainties inherent in modelling water use, a deterministic method is not the best approach to analysing the presented water use problem. Therefore, a stochastic model was developed in this study to model water use as was done by Blokker et al. (2010) and Cahill (2010), with probability distributions being used to describe the model input parameters. The model developed in this study was entitled the litre per capita per day (LCD) model. The parameter uncertainties for the LCD model include lifestyle habit, location and climate, household age and household size, all of which vary from area to area.

The LCD model was developed in this study to stochastically model the expected domestic water requirements for a single-person household, at different lifestyle levels. The following steps were followed to develop the model:

1. All water use activities that would occur in a household were identified. The water use activities identified in this study, and the key used for identification, are summarised below:

    - Toilet (T)
    - Shower (S)
    - Bath (B)
    - Clothes washing (CW)
    - Dishwasher (DW)
    - Washing dishes by hand (WDH)
    - Drinking water (DR)
    - Cooking (C)
    - Eyecare (EC)
    - Hand washing (HW)
    - Shaving (SH)
    - Brushing teeth (BT)
    - Cleaning the house (CH)
    - Wiping kitchen counter (WKC)
    - Indoor Plants (IP)
    - Pets (P)
    - Irrigation (IR)
    - Carwash (CW)
    - Swimming Pool (SP)
    - Leaks (L)
    - Miscellaneous (MS)

2. Probability distributions were determined for each parameter used to determine the water requirement for each water use activity. The assignment of the probability distributions is further discussed in Chapter 6.
3. Once probability distributions were assigned to each model input parameter, the relevant parameters for each water use activity were used to determine the water requirements for

that water use activity. The parameters used to calculate water requirements are generally a combination of frequency, duration, flow rate and volume per event. If the flow rate and duration of the water use activity are known, the volume is calculated by multiplying the two values together. If the event volume is known, no further calculations are required to determine the volume per event. However, to determine the volume per capita per day, the event volume is multiplied by the frequency per capita per day.

4. Sample values were taken from each distribution to simulate a household. The water use for that sample household was determined.
5. A Monte Carlo Simulation creating 100 000 sample households was run, allowing for a resultant water use distribution to be modelled.

The ultimate lifestyle level was developed first. The ultimate lifestyle takes all water use activities into consideration, without any restrictions. The stochastic development of the ultimate lifestyle level is further explained in Chapter 6. The subsequent lifestyles are modifications of the ultimate lifestyle level and are discussed in Section 6.5.

3.2 Selection of single-person household

Previous studies have found that per capita water consumption decreases with increased household size (see section 2.3). The decrease in per capita consumption can be modelled using input values from literature. However, the initial single-person household water use is required. Therefore, this study focused on determining water use for a single-person household, as the result is the most conservative water use estimation. The single-person per capita consumption result can subsequently be adjusted for household size.

In order to determine the per capita consumption for each lifestyle level and each household size, all available measured South African data was compiled. Attention was given to include only values that relate directly to actual individual household consumption where the number of occupants was also known. Per capita consumption values based on generalised information (e.g. census or population) were excluded; the results were compared to international publications and to generalised values. A summary of the compiled data is given in Figure 3.1.

The measured data was a compilation of five different data sets, including a study of residences in a gated housing estate in Johannesburg (Ilemobade et al., 2018); data collected during an ongoing study from 17 University of Stellenbosch student homes; data from upmarket homes in Hermanus, Western Cape and 20 low income houses in Kleinmond (Pretorius et al., 2019); as well as data from a few relatively low-income households in Eastwood, Pietermaritzburg (Smith, 2010). An average of all the water use values for each household size was calculated and represented as "SA measured average". Once all the data was compiled various curve fits were considered. The data were filtered according to the level of service in each case. For the purpose of this study, only the highest level of service was considered. The Pretorius et al. (2019) and Smith (2010) data was found to represent a low level of service, while the Ilemobade et al. (2018), Hermanus (Pretorius et al., 2019) and Stellenbosch (SU houses) data were found to represent a high level of service. Consequently, only the latter three sets of data were used for fitting the trend curve. A trendline was fitted to the data and used as a basis to derive water use values as a function of household size for each lifestyle level. Equation 3.1 was found to best represent the per capita consumption for a household when fitting a trendline to the Ilemobade et al. (2018), Hermanus (Pretorius et al., 2019) and Stellenbosch (SU houses) data. Equation 3.1 was used to modify the single-person household results of the LCD model for different household sizes (see section 8.2). For example, if the single-person household per capita consumption was found to be 250 L/c/d, Equation 3.1 would be used to calculate the per capita consumption trendline for increasing household size, as shown in Figure 3.1.

$$Per\ capita\ water\ use = SPC \times d^{-0.439} \qquad \textit{Equation 3.1}$$

Where: SPC = per capita consumption for single-person household

d = household size

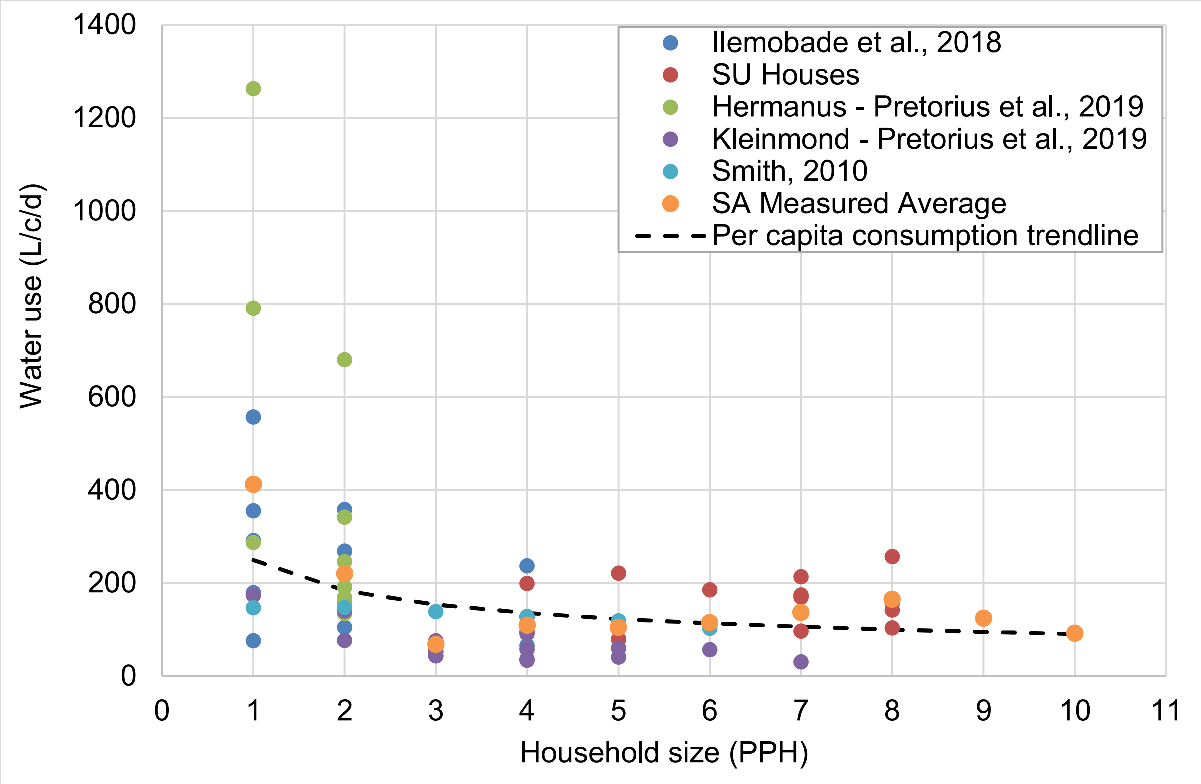

Figure 3.1: Measured South African per capita water use data

3.3 LCD model survey

Extensive or valuable literature could not be found for every parameter describing household water activities. In order to enrich the literature data and address any missing data, a survey was developed to determine water use behaviours with regards to certain water use activities. The survey was developed and underwent the applicable ethical approval, in line with the University of Stellenbosch research ethics requirements. The survey was in digital format allowing participants to complete the survey online, allowing for global distribution of the survey. The survey was distributed both privately and corporately in hopes of the greatest response. A total of 171 participants started the survey, with 160 completing all the questions. The survey was completed by participants with an age range of 18 to over 55, from 5 continents and 11 countries, providing global insight into water use behaviour. The survey questions can be found in Appendix B.

The survey findings are presented in Appendix B, with several of the most interesting deductions listed below:

- The frequency with which the respondents felt it necessary to shower decreased under the ABC conditions, with 8% of the respondents being willing to shower once a week;

- Similarly, hair washing frequency, as well as shaving, were seen as water use activities that could have their frequencies reduced under ABC conditions;
- 48.7% of respondents felt their lifestyles fell within the esteemed needs water use category, while only 17.1% felt they lived within the ultimate consumption category. However, 30.1% responded that they strive to live in the ultimate consumption category;
- Conversely, 2.6% of respondents believed they lived within the physiological needs category, yet 4.5% responded that they strived to live within the physiological needs category.

3.4 Verification of model results

The model was verified for reasonableness by reviewing logical actions and limits, both deterministically and stochastically (see section 8.1). The model could not be validated due to a lack of recorded data at the required temporal and spatial scale. Furthermore, the model results were compared to per capita consumption values found in literature, as well as expected consumption values calculated using available online water use calculators.

3.5 Distribution and sampling of model input parameters

A total of 135 input parameters were used to describe the water use activities in the final LCD model. Due to the inherent variability of water use activities, a single average value was not used to define the parameters that contributed to calculating the water used for each water use activity; instead, a probability distribution was used to describe each parameter. The probability distributions were taken from end use studies or other literature sources discussed in Chapter 5, where available. In the case of scarce or non-existent literature values, engineering estimates or the LCD model survey results were used. A comprehensive description of each input parameter, including appropriate values, distributions, unit of measures and origin of data is presented in Appendix C. Once parameter distributions had been defined, a model skeleton for each lifestyle level was created. Water use for one single-person household (i.e. one Monte Carlo sample) was generated by taking random samples for each parameter used to calculate water use. Random sampling was taken from a cumulative distribution function (CDF) of the defined probability distribution function (PDF) for each parameter. For example, Figure 3.2 shows the density and cumulative distribution functions for clothes washing frequency. Random sampling is done by generating a random number between 0 and 1 which correlates to a non-exceedance probability. The non-exceedance probability is then used to determine the corresponding parameter value. For example, if a random value of 0.5 was drawn, the corresponding clothes washing frequency would be 0.31 events/c/d. @Risk software was used to perform the random sampling as a Monte Carlo simulation of 100 000 samples was used for the model.

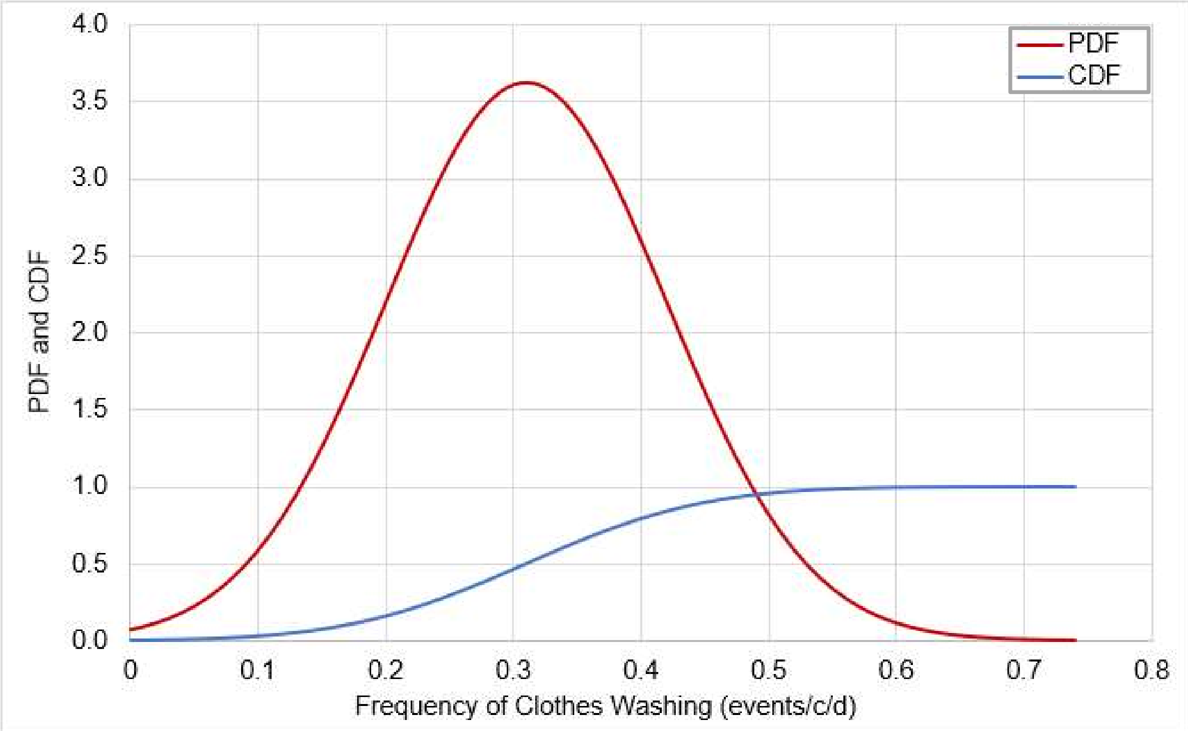

Figure 3.2: Probability density and cumulative distribution of clothes washing frequency

3.6 Interdependency of events

A number of water use activities were deemed to be inter-dependent in this study; meaning a water use activity will or will not happen because of another activity happening. For example, the use of a toilet will most often result in a hand washing event if recommended hygiene practice is followed. A summary of the assumed interdependent water use activities, as used in the LCD model, are given in Table 3.1. All other water use activities were considered independent in the development of the model.

Table 3.1: Assumed interdependencies between water use activities

(1) Water use activity	(2) Dependent on	(3) Type of dependency
Washing hands	Toilet use	2 leads to 1
	Food preparation frequency	2 leads to 1
	Food eating frequency	2 leads to 1
	Presence of pets	if 2 is true, 1 will be affected

Bathing for cleaning	Showering	if 2 is true, 1 cannot be true
Bathing for relaxation	Showering	only if 2 is true, 1 can occur
Frequency of hand washing dishes	Presence of a dishwasher	2 will affect 1

3.7 Software used for model development

Software that had statistical modelling parameters capable of computing multiple Monte Carlo simulations was required for the development of the LCD model. The @Risk software used in developing this model is a risk analysis and simulation add-in for Microsoft Excel (Palisade Corporation, 2016). @Risk uses Monte Carlo simulation to determine the distribution of the likelihood of an event occurring. The software contains many distributions which can be used to describe the characteristics of each parameter contributing to the water used for each water use activities. @Risk software also allows for truncation of data at upper and lower bounds. In some cases, this function was made use of to eliminate the possibilities of extreme outliers. Once a distribution has been assigned to each parameter, a Monte Carlo simulation can be run to evaluate the distribution of the total water use for each modelled lifestyle level. Along with the distribution, the @Risk software can give the characteristics of the distribution, such as the mean, the interquartile ranges, the minimum and maximum values. @Risk can also provide information such as the parameters that have the greatest and the smallest impact on water use.

The following parameters subsets were used when developing the model: frequency of events, flow rate, duration of event, volume of event and household size. The parameters were categorised into discrete random variables and continuous random variables.

The following parameter subsets were identified as being discrete random variables:

- Frequency of event
- Household size

The following parameter subsets were identified as being continuous random variables:

- Flow rate
- Duration of event
- Volume of event

Frequency of events is considered to have a discrete distribution as an event cannot occur a non-integer amount of times. Certain events occur in a time scale greater than a day, therefore, the frequencies were converted to daily frequencies, resulting in a non-integer frequency value.

4 Probability Theory

4.1 Random variables

Studies are often performed on a subset of a population. That subset is termed a sample in statistics and any possible outcome within that sample is termed the sample space, denoted by *S*. A random variable, *X*, is a variable that obtains one value from *S,* denoted by *x,* when a certain set of conditions, π, are realised (Holicky, 2009). Random variables can be split into discrete random variables and continuous random variables.

Discrete random variables are defined as variables whose values make up a finite set of values i.e. they can only take a countable number of values (Montgomery and Runger, 2014). For example, if *X* is the number of people in a class, *X* is a discrete random variable as the only possible values of *X* are {*X* = 1, 2, 3, 4, …} as you cannot have a fraction of a person.

A continuous random variable can take on any real number (Montgomery and Runger, 2014). For example, if *X* is the distance travelled to work, *X* is a continuous random variable as the distance can be any number on the number line, greater than 0.

4.2 Measures of central tendency

A central tendency is a statistical measure which is a single value that best represents a distribution of values. The measure where the majority of values lie within the distribution giving the central point of the data (Montgomery and Runger, 2014). The three most common measures of central tendency used in statistics are the mean, median and the mode of which the mean is the most relevant to this study.

The mean is a representation of the overall average of the sample. It should be noted that the mean is sensitive to outliers as it changes with a change in one variable and it considers all variables in the sample regardless of how far of an outlier they may be. Some advantages of the mean are that the sample mean gives a better representation of the population than the median or mode. The mean can also be manipulated algebraically (i.e. it can be placed into a normal algebraic equation) and the means of subgroups can be combined as long as they are weighted correctly (Howell, 2007).

The median is the middle data point of the distribution when all the values are arranged in an ascending or descending order, hence the median is the 50th percentile (Manikandan, 2011). The advantage of the median is that it is easy to determine and comprehend and it is not skewed by outliers. However, some of the disadvantages of the median is that does not take into account how scattered the data is, it cannot be used for future algebraic calculations and the medians of two pooled data sets cannot be used to express the median of the pooled data set, i.e. the median of the the combined data of the two data sets cannot be determined from the median of the individual data sets (Manikandan, 2011).

The mode is described by Manikandan (2011) as “the most frequently occurring value in the data set. The mode is generally only used as a summary statistic when describing a binominal distribution, which occurs when there are two modes. The advantages of the mode are that it can be calculated easily, and it is the only central tendency that can be used for data measured on a nominal scale. The disadvantage of the mode, as with the median, is that it cannot be used in algebraic calculations.

4.3 Measures of variability

The measure of central tendency gives an idea of the middle of the data. However, the central tendency measures often give limited information about the data set as it does not give an idea of how widely spread the data is around the central point. Two different data sets can have the same mean and median but have very different ranges in which the rest of the data sits. Therefore, it is important to have a measure of the variability of the values within the data set. The most commonly used measures of variability are range, percentiles, variance and standard deviation, of which the standard deviation is the most relevant to this study (Montgomery and Runger, 2014).

The range is the difference between the lowest and the highest values in the data set. It is a representation of common scenarios such as price ranges. However, it is less useful in statistics as it only considers the outliers which could give an inaccurate representation of the variability of the data. In order to negate the effects of the outliers, subsets of the range have been created, most notably the interquartile range. The interquartile range discards the upper and lower 25% of data, giving the variability of only the middle 50% (Howell, 2007).

A percentile divides the data distribution into 100 equal groups giving a relative position within a data set. The k^{th} percentile is the value that splits the data set into a bottom set containing the first k percent of the data and an upper set containing the rest of the data (Montgomery and Runger, 2014)

The standard deviation is simply the positive square root of the variance. The standard deviation is a measure of the dispersion of the data points around the mean, meaning it is the average distance between the mean and values in the data set. A high standard deviation means the data points are widely spread around the mean, while a low standard deviation (i.e. closer to zero) means there is a low dispersion around the mean.

4.4 Frequency distribution

When there is a large amount of data present in a data set, frequency distributions are often used to make the data comprehensible to the user. A frequency distribution is created by tabulating each unique data value in the data set along with its associated frequency of occurrence. The relative frequency is the frequency of a value divided by the size of the data set. Multiplying the relative frequency by 100 gives the percentage chance of occurrence (Montgomery and Runger, 2014).

A frequency distribution is most frequently graphically presented by means of a histogram. A histogram represents the intervals of the data in bars along its x-axis. The height of the bars usually represents the frequency while the width of the bars represents the interval size of the data. For discrete data, the centre of the bar is on the *x* data point while the size of the bar is the distance between successive *x* values. For continuous data, intervals or classes are created for the measurement axis. As the measurement intervals are made smaller the bars get closer together up until the point where they are so close that they become a smooth curve, this curve is called a density curve (Howell, 2007).

4.5 Probability mass and density functions

The probability mass function, denoted by f(*x*), is defined as the probability that the random variable *X* will take on the value *x* and is shown by Equation 4.1. The probability mass function determines the probability of occurrence for a discrete random variable where there is a countable number of possible values.

$$P(X = x) = f(x) \qquad \textit{Equation 4.1}$$

For continuous random variables the probability that *X* takes on the value *x,* is 0. Therefore, an interval needs to be created such that the probability that *X* occurs within that interval on the real number line can be determined. The function to determine the probability of *X* taking on a value between *x* = a and *x* = b is defined as the probability density function (PDF) and is expressed mathematically by Equation 4.2 (Montgomery and Runger, 2014). The graph of f(x) is referred to as the density curve and the probability that *X* is between a and b is represented graphically as the area under the curve between a and b.

$$P(a \leq X \leq b) = \int_a^b f(x)\,dx \qquad \textit{Equation 4.2}$$

4.6 Cumulative distribution

The cumulative distribution function (CDF), F(x), for a continuous random variable, gives the probability that the realisation of the random variable *X* will be less than the value *x*. The cumulative distribution function (CFD) is determined by integrating the probability density function (PDF) between negative infinity and *x,* expressed mathematically by Equation 4.3 (Montgomery and Runger, 2014). A PDF and the associated CDF for a continuous random variable is shown in Figure 4.1.

$$F(x) = P(X \leq x) = \int_{-\infty}^{x} f(t)dt \qquad \textit{Equation 4.3}$$

A cumulative density function for a discrete random variable is the sum of the probabilities that are less than or equal to *x*. A PDF and the associated CDF for a discrete random variable is shown in Figure 4.2.

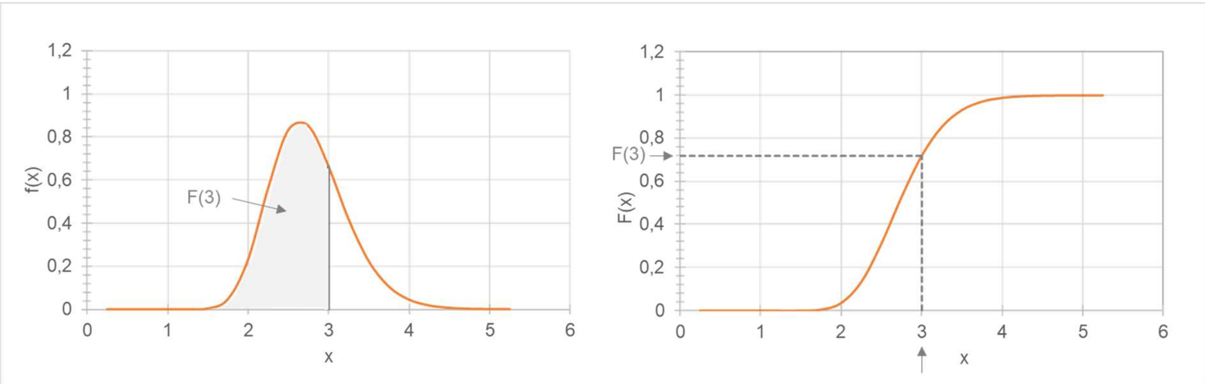

Figure 4.1: PDF and CDF for a continuous random variable

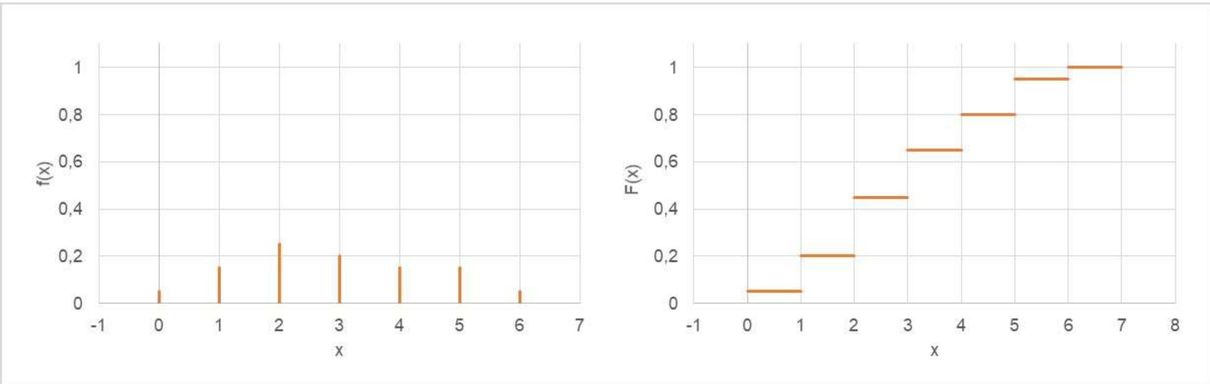

Figure 4.2: PDF and CDF for a discrete random variable

4.7 Distribution parameters

Since all data sets have different probability density functions it is often hard to mathematically describe each unique PDF. However, there are several predefined theoretical distributions that are mathematically described by which most PDFs will conform, with some margin of error. This means that should the PDF fit one of the theoretical distributions, the mathematical characteristics of that distribution can be applied to that data set.

Theoretical distributions belong to a family of distributions as they can take on a number of different forms; which are commonly described by three parameters, namely the shape parameter, the scale parameter and the location parameter. It is important to note that not all distribution families are described by all three parameters.

The shape parameter, defined by α, affects the overall shape of the distribution allowing for a variety of data sets to be modelled (Montgomery and Runger, 2014). The scale parameter, denoted by β, will scale the distribution by stretching or compressing the distribution. As the scale parameter increases above one, the distribution will be compressed along the y-axis, meaning the data points will lie over a greater section along the x-axis and a lower section on the y-axis. As the scale parameter approaches zero the distribution will be stretched up along the y-axis, meaning the data points will lie in a narrower band on the x-axis and wider band on the y-axis. The location parameter, denoted as γ, simply shifts the distribution to the left or right of the standard distribution (Montgomery and Runger, 2014). The effect of the location parameter is best explained with a normal distribution. The standard normal distribution has its mean positioned at 0, the location parameter will shift the location of the mean by the value of the location parameter, eg. a γ of -2 would shift the mean location to -2.

4.8 Theoretical probability distributions used in the LCD model

The LCD model set up in this study made use of a number of different theoretical distributions to model various water use activities and their related parameters. It is common in water use modelling to use uniform and/or lognormal distributions as they tend to model water use behaviour both simplistically and accurately. The normal distribution is less common as it allows for values below zero, which is considered irrelevant for water use values. The Bernoulli distribution, described in Table 4.1, is commonly used when determining the probability of a population performing a water use activity or owning a water consuming appliance. The uniform, triangular, normal, lognormal, Poisson, Bernoulli and discrete distributions were used in this study. A brief summary of the parameters for each distribution as per the MS @Risk user manual is presented in Table 4.1 (Palisade Corporation, 2016).

Table 4.1: Summary of parameters for statistical distributions used for the LCD model

Uniform distribution		
Parameters	min max min < max	continuous boundary parameter continuous boundary parameter
Domain	min ≤ x ≤ max	continuous
PDF	$f(x) = \frac{1}{\max - min}$	
CDF	$F(x) = \frac{x - min}{\max - min}$	
Mean	$\frac{\max + min}{2}$	
Variance	$\frac{(\max + min)^2}{12}$	
Triangular Distribution		
Parameters	min m.likely max	continuous boundary parameter min < max continuous mode parameter min ≤ m.likely ≤ max continuous boundary parameter
Domain	min ≤ x ≤ max	continuous
PDF	$f(x) = \frac{2(x-min)}{(m.likely-min)(max-min)}$ $f(x) = \frac{2(max-x)}{(max-m.likely)(max-min)}$	min ≤ x ≤ m.likely m.likely ≤ x ≤ max
CDF	$F(x) = \frac{(x-min)^2}{(m.likely-min)(max-min)}$ $F(x) = 1 - \frac{(max-x)^2}{(max-m.likely)(max-min)}$	min ≤ x ≤ m.likely m.likely ≤ x ≤ max
Mean	$\frac{\min + m.likely + max}{3}$	
Variance	$\frac{\min^2 + m.likely^2 + max^2 - (max)(m.likely) - (m.likely)(min) - (min)(max)}{18}$	
Normal Distribution		
Parameters	μ continuous location parameter σ continuous scale parameter	 σ > 0

Domain	-∞ < x < +∞	continuous
PDF	$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$	
CDF	$F(x) = \frac{1}{2}\left[erf\left(\frac{x-\mu}{\sqrt{2}\sigma}\right) + 1\right]$	
Mean	μ	
Variance	σ^2	
Log Normal Distribution		
Parameters	μ continuous location parameter σ continuous scale parameter	μ > 0 σ > 0
Domain	0 < x < +∞	continuous
PDF	$f(x) = \frac{1}{x\sqrt{2\pi}\sigma'} e^{-\frac{1}{2}\left(\frac{\ln x-\mu'}{\sigma'}\right)^2}$	
CDF	$F(x) = \Phi\left(\frac{\ln x - \mu'}{\sigma'}\right)$ $\mu' \equiv \ln\frac{\mu^2}{\sqrt{\sigma^2+\mu^2}}$ $\sigma^2 \equiv \sqrt{\ln\left[1+\left(\frac{\sigma}{\mu}\right)^2\right]}$	
Mean	μ	
Variance	σ^2	
Poisson Distribution		
Parameters	λ mean number of successes	continuous λ > 0
Domain	0 < x < +∞	discrete integers
PDF	$f(x) = \frac{\lambda^x e^{-\lambda}}{x!}$	
CDF	$F(x) = \mathrm{e}^{-\lambda}\sum_{n=0}^{x}\frac{\lambda^n}{n!}$	
Mean	λ	
Variance	λ	
Bernoulli		
Parameters	*p* continuous parameter	0 < *p* < 1
Domain	x ∈ {0,1}	discrete integers
PDF	f (x) = 1− p	for x = 0

	f (x) = p f (x) = 0	for x =1 otherwise
CDF	F(x) = 0 F(x) = 1− p F(x) = 1	for x < 0 for 0 ≥ x < 1 for x ≥ 1
Mean	*p*	
Variance	*p*(1− *p*)	
Discrete		
Parameters	{x} = {x1, x2, …, xN} {p} = {p1, p2, …, pN}	array of continuous parameters array of continuous parameters
Domain	x ∈ {x}	discrete
PDF	f (x) = p_i f (x) = 0	for x = x_i for x ∉ {x}
CDF	F(x) = 0 for x < x_1 F(x)= $\sum_{i=1}^{s} p_i$ F(x) = 1 The arrays are assumed to be ordered from left to right. The p array is assumed to be normalized so that they sum to 1.	 for $x_s \le x < x_{s+1}$, s < N for x ≥ x_N
Mean	$\sum_{i=1}^{N} x_i p_i \equiv \mu$	
Variance	$\sum_{i=1}^{N} (x_i - \mu)^2 p_i \equiv V$	

5 Water Use Activities

5.1 Relevance to model

The following chapter contains literature regarding household water use activities. Water use values and distributions identified during the following knowledge review were used in the development of the LCD model. The water use activities were categorised as indoor, outdoor or miscellaneous activities based on their typical location of occurrence.

5.2 Water requirements for water use activities - indoor

5.2.1 Drinking

Water is needed for hydration, body temperature regulation, lubrication of joints and to keep tissue moisturised. Water also aids with digestion and removing toxins and wastes from the body (British Nutrition Foundation, 2018). Chan et al. (2002) found that the risk of fatal coronary heart disease for both men and women decreased with consumption of at least 1 L of water a day. A study by Kliener (1999) also found some evidence that increased water intake reduces the risk of colon and breast cancer.

The volume of water required by an individual varies depending on factors such as weight, climate, gender, occupation, level of physical activity and health needs. Drinking water generally includes any water that is consumed through drinking, whether it be plain water or water in a mixed or steeped drink. The argument has been made by Kleiner (1999) that diuretics, such as coffee, can lead to dehydration rather than hydration, however, this has not been verified. Alcohol is generally excluded from the calculation of drinking water as it has a diuretic effect on the body and leads to a greater water loss than is gained from consumption (British Nutrition Foundation, 2018). Kliener (1999) recommends an average daily water use of between 2.2 L and 2.9 L for males and females respectively, of which approximately a third would be indirect consumption with food. White et al. (1972) suggests that in order to reduce the risk of kidney stones, a minimum of 1.5 L urine should be passed each day. Based on these studies and further investigation, the World Health Organisation (2003) determined a normal direct drinking water consumption requirement of 2 L/c/d. Differing lifestyles and needs may necessitate different drinking water requirements. Physical labourers working in hot weather conditions require as much as 4.5 L/c/d and pregnant and lactating women require 4.8 L/c/d and 5.5 L/c/d, respectively (WHO, 2003). Even though the daily water consumption, recommended by The World Health Organisation (WHO, 2003), is 2.0 L/c/d, many studies throughout Europe, North America, Asia and Australia have found that water consumption for drinking ranges between 0.5 L/c/d and 1.65 L/c/d (An et al., 2011; Dangendorf, 2003; George and Suriyanarayanan, 2016; Gofti-Laroche et al., 2001; Hunter et al., 2004; Kaur et al., 2004; Kyunghee et al., 2010; Mons et al., 2007; Roberson et al., 2002; USEPA, 2000), although some of the studies cited excluded hot beverage consumption (Chapagain and Hoekstra, 2003). Duan et al., 2010; Hossain et al., 2013; Xiao et al., 2012 reported consumption of greater than 2.0 L/c/d, with the highest average consumption being 3.12 L/c/d.

5.2.2 Toilet

Flushing toilets were first invented in 1596 by Sir John Harrington, however, the toilet only became common in the late 1770s, with Alexander Cumming being granted the patent for the toilet in 1775 (Lambert, 2018). The flushing toilet remained a luxury item until the late 19th century (Lambert, 2018). Currently, developed countries have a variety of advanced toilet designs, with toilet flush volumes as low as 2.0 L/flush; however, many developing countries lack any toilet infrastructure or sewer networks (Fane and Schlunke, 2008).

Toilet flushes are one of the three largest contributors to indoor water use, contributing to up to 27% of indoor water use (Lee et al., 2012; Mayer et al., 1999; Roberts, 2005). The average per capita daily water use for toilets varies between 37.3 L/c/d (Aquacraft, 2015) and 113.6 L/c/d (Baumann et al., 1998). Therefore, targeting toilet use is common practice when trying to reduce indoor water use.

Older toilet cisterns vary in size depending on age and location. Reported average old toilet flush volumes vary from 11.0 to 27.0 L/flush (Aquacraft, 2015; Fane and Schlunke, 2008; Jacobs, 2004; Mayer et al., 1999; Whitcomb, 1990). The more modern single flush toilets have an average flush volume of 9.0 L/flush (Blokker et al., 2011).

The most effective and widely used method of reducing toilet water use is the introduction of the dual-flush toilet. Consequently, in the early 2000s, many developed countries implemented rebate programmes to encourage residents to retrofit their old toilet cisterns with new dual flush toilet systems (Cahill, 2010; de Oliveira Junior, 2002; Ferrara, 2008). While other countries implemented new bylaws or policies prohibiting the sale of toilets with flushes greater than a certain volume (DeOreo and Mayer, 2012; Fane and Schlunke, 2008). Grafton et al. (2011) found that, when considering all water saving devices, the only statistically significant water saving device is a dual flush toilet, while, Ferrara (2008) found that both low flow showerheads and dual flush toilets have a substantial impact on water savings, with a water use reduction of 8% and 10% for each respective device. Therefore, it is clear that dual flush toilets, as they are currently used, are effective in reducing water use, while the effectiveness of other water saving devices is unknown.

The dual flush toilet was designed by Bruce Thompson in the late 1970s and first implemented in 1981 by Caroma in an attempt to alleviate stress on the water system in drought-prone Australia (SLSA, 2006). The first dual flush toilet had a large/small flush ratio of 11.0/5.5 L/flush. The common dual flush toilet was later reduced to 6.0/3.0 L/flush (SLSA, 2006). Modern dual flush toilets in Australia can use as little as 4.5/3.0 L/flush for large/small flushes, while it has been reported that some Scandinavian countries are using 3.0/2.0 L dual flush toilets in holiday homes where toilet use is less frequent (Fane and Schlunke, 2008). Toilets sold commercially in South Africa have flush volumes that range between 9.0 L/flush (single flush toilets) and 2.5/4.5 L/flush (dual flush toilets). A review of international online retail websites was done to determine the percentage of various toilet types sold in different countries. A summary of the percentages of toilet types sold in each region is given in Table 5.1. The percentage values were calculated by dividing the total number of a type of toilet sold by the company, as reported online, by the total toilets sold by the company.

Table 5.1: Distribution of different toilets sold by retail outlets

Country	Outlet	Toilet Type	% sold	Reference
SA	CTM	2.5/4.5 dual	10	CTM (2019)
		3.0/6.0 dual	70	
		6.0 single	20	
	Builders	9.0 single	10	Builders (2019)
		6.0 single	52	
		5.0 single	5	
		3.0/6.0 dual	33	
UK	Graham plumbers merchant	3.0/6.0 dual	9	Grahan plumbers merchant (2017)
		4.0/6.0 dual	33	
		2.6/4.0 dual	38	
		6.0 single	20	
Asia - Singapore	Bathroom warehouse	2.5/3.5 dual	15	Bathroom Warehouse, (2019)
		2.8/3.8 dual	61	
		3.0/4.5 dual	24	
	Kohler	2.6/4.0 dual	43	Kohler (2019)
		3.0/4.5 dual	43	
		3.0/6.0 dual	14	
South and North America	Kohler	2.1/4.2 dual	32	Kohler (2019)
		2.6/4.0 dual	8	
		3.0/6.0 dual	56	
		6.0 single	4	
International	Roca	3.0/4.5 dual	65	Roca (2019)
		3.0/6.0 dual	35	

Studies into the effectiveness of dual flush toilets show that there is a significant decrease in water use with the installation of dual flush toilets. A reduction in water use of approximately 18% to 27% has been found after retrofitting dual flush toilets (Keeting and Howarth, 2003; Keating and Lawson, 2000; Oliveira et al., 2009). However, Valencio and Gonçalves (2019) found that any toilet with a flush volume less the 6.0 L/flush is not effective in saving water as more than one flush is often required to clear the bowl, resulting in an overall higher water use. One of the potential disadvantages of toilets with a relatively low flush volume is that the quantity of water being flushed into the waste system is significantly reduced. A reduction in water in the drainage network can have negative effects on the system as a whole because the solids are unable to move easily down the system causing blockages (Valencio and Gonçalves, 2019). Littlewood et al. (2007) found that an ultra-low flush toilet has minimum effect on a drainage system using a 50 mm diameter pipe, however, a suggestion was made to modify buildings to accommodate ultra-low flush toilet systems should they become the norm in the future.

Other water-efficient alternatives to dual flush toilets include the urine separating toilet, the air-assisted flush toilet and the vacuum toile. Urine separating toilets are toilets with two separate bowls to separate urine and faeces. The benefit of urine separating toilet is that it allows for a flush as low as 0.2 L/flush in the urine bowl and a 4 to 6 L flush in the faeces bowl (Fane and Schlunke, 2008). The urine from the urine separating toilets is often high in phosphorous and other nutrients and therefore, in view of further environmental conservation it is often used as fertiliser (Cordell, 2006; Fane and Schlunke, 2008; Lienert and Larsen, 2009). Urine separating toilets have been used for years in Asia and have become popular in Sweden over the last 20 years (Cordell, 2006; Lienert and Larsen, 2009; Hanæus et al., 1997). Urine separation toilets lack market penetration due to the following drawbacks: health risks, blockages, phosphate precipitation, higher maintenance requirements and the requirement of sitting to urinate for effective use (Lienert and Larsen, 2009).

The air-assisted flush toilet is a UK designed toilet which uses pressurised air to assist with toilet flushing and thus reducing the volume of water needed per flush to as little as 1.5 L (Fane and Schlunke, 2008). The toilet design requires the toilet lid to be put down before flushing to create an air seal. The flush water volume is then released, followed by pressurised air to displace the excrements in the bowl and any remaining water filled the water trap (Propelair, 2007). The complicated mechanisms required for the functioning of the toilet and the extra step of closing the toilet seat could be a deterrent for consumers. The vacuum toilet, common on aeroplanes, works on a similar principle with the toilet contents being removed from the toilet bowl and transported using differential air pressure (i.e. a vacuum) with water only being required for cleaning the bowl (Li et al., 2001). Approximately 1 L/flush of water is used for vacuum toilets (Li et al., 2001). There has been little success in implementing vacuum toilets into residential environments (Asphipala and Armitage, 2011; Taking, 2017).

Daily toilet water use is governed by flush volume and flush frequency. Flush volume is solely dependent on the toilet type in the household. However, the flush frequency can vary significantly between people and households and is sometimes targeted as a means to reduce water usage during times of restrictions or for general conservation purposes (Lute et al., 2015). The average toilet flush frequency is between 4 and 5 flushes/c/d (Buchberger and Wu, 1995; DeOreo and Mayer, 2012; Friedler et al., 1996; Roberts, 2005; Rosenberg, 2007; Hussien et al., 2016), of which 1.15 flushes/c/d were found to be faeces related in one study (Friedler et al., 1996). The average flush frequency can vary from the norm for people with medical conditions or for the young and old. It has been suggested that flush frequency can be decreased as flushing may not be necessary when only urine is in the toilet bowl. However, there are both hygienic and social deterrents to the idea (Lute et al., 2015). A study conducted on a sample population of 1008 in the United States revealed that only 63% of participants flushed their toilet every time after urination, 22% flushed most of the time and 9% only flushed half the time. The primary reason for not flushing every time was for environmental or money-saving reasons (Lute et al., 2015). Therefore, it can be deduced that some people may be comfortable with a reduced flushing frequency. For hygienic reasons, the toilet should be flushed after defecation as faeces contain disease-causing bacteria and have a foul odour (Ebrahim and Randall, 2019). In view of maintaining hygiene and assuming an average defecation rate of one to two times a day as per a study by Heaton et al. (1992), a reasonable absolute minimum flush frequency of 2 flushes/c/d can be deduced.

5.2.3 Shower

Showers or baths are used for washing the body. The frequency of washing is dependent on a variety of factors explained by Barnes (2019), including but not limited to:

- Age – a baby or child has not developed an immune system equal to that of an adult and, thus, requires more frequent washing to prevent illness. Similarly, the elderly are at more risk for infection and will require more frequent washing;
- Overall health – a healthy person will require washing less frequently than a person with a weakened immune system due to illness, chronic conditions or an unhealthy lifestyle;
- Exposure risk – as the risk of exposure to contaminants increases (i.e. the overall hygiene of the living environments), the more the frequency of body washes needs to increase;
- Quality of water – suboptimal water quality will increase the need to wash;

- The provision of sanitation requirements – the standard of the toilet facilities, access to anal wipes as well as access to soap and water for cleaning hands will all affect body washing frequency; and
- Religious or occupation requirements – prescribed sanitation or body washing requirements are associated with different occupations or religious practices.

Showers contribute to between 16.8% (Kappel and Grechenig, 2009) and 40% (Schleich and Hillenbrand, 2009), but usually about 30% of indoor water use (Carragher et al., 2012; Lee et al., 2012; Roberts, 2005). The use of showers varies amongst different countries, as some eastern countries, such as Japan and India, predominantly use baths and therefore have a low shower use (Sadr et al., 2016; Hayasaka et al., 2010). Browne et al. (2014) found, in the sample group for the study based in the UK, that preference between bathing and showering as a means to get clean has changed over time from bathing to showering, with only 17% of the study population never showering, in comparison to 50% never bathing. Of the population that bath, it is usually an occasional activity and not the regular body washing preference. This preference was found to be true amongst the younger population in a Japanese study, suggesting that even in non-western countries there is a move towards using showers over baths (Hayasaka et al., 2010). A study in Portugal found that 88% of the study population prefers showers over baths (Matos et al., 2013).

Shower frequency depends on a variety of factors, such as the presence of a bath, age, occupation, activity level and medical or religious needs. Children affect shower frequency significantly as they often bath rather than shower. Roberts (2005) found a reduction in household shower frequency of 0.35 events/d from 0.94 events/d with the presence of children under twelve. Similarly, the elderly are also more likely to take baths rather than showers and may shower or bath less frequently as they are less active (Schleich and Hillenbrand, 2009). DeOreo et al. (2011) found that people who work out of the house have more frequent showers.

Studies have shown that the average shower frequency is approximately 0.85 showers/day with a standard deviation of 0.49 showers/day (Buchberger and Wu, 1995; Cahill, 2010; Roberts, 2005; Blokker et al., 2010). However, it has been found to be common for people to shower up to twice a day in some areas (Hand et al., 2005).

The duration of a shower event is extremely variable as different people have different requirements when it comes to shower duration. Some people use a shower as a time to relax, which means they may take longer in the shower than someone who uses the shower purely for washing purposes. Women often have longer hair than men which needs to be washed, often requiring a longer time in the shower. Additionally, the average shower duration has been found to differ depending on the use of a normal or low flow showerhead. Typical shower durations range from about 6.8 minutes (Buchberger and Wu, 1995; Gleick et al., 2003; Mayer et al., 1999; Roberts, 2005) to about 13.7 minutes (Jacobs and Haarhoff, 2004a; Wong and Mui, 2008), averaging approximately 8.5 minutes (Blokker et al., 2010; DeOreo et al., 2011; Gleick et al., 2003; Hand et al., 2005; Mayer et al., 1999; Rosenberg, 2007). Jacobs and Harhoff (2004) noted exceptionally short shower durations of as low as 2 minutes. It should be noted that the lower shower durations are typically only for showers with normal showerheads. Conversely, longer shower durations have been found to coincide with showers with low flow showerheads (Babooram and Hurst, 2010; Kappel and Grechenig, 2009; Rosenberg, 2007).

Showers are high water consumers; consequently, low flow showerheads are commonly suggested as a means to reduce water use. Studies in Canada show that around 55% of households have installed low flow showerheads (Grafton et al., 2011). However, there is a dispute as to whether low flow showerheads have any significant effect on water use. Studies in California, Florida, Hong Kong, Goleta and Santa Barbara found low flow showerheads to be effective in saving water (Ferrara, 2008; Grafton et al., 2011; Wong et al., 2016), yet, a study in Colorado found that the low flow showerheads do not significantly reduce water use as the shower duration with a low flow showerhead is often longer than that with a normal showerhead, resulting in an equivalent water use (Grafton et al., 2011). The average flow rate of a standard shower head is 11 – 27 L/min (Babooram and Hurst, 2010; Buchberger and Wu, 1995; Jacobs and Haarhoff, 2004a; Kappel and Grechenig, 2009; Rosenberg, 2007; Wong and Mui, 2008) while the average flow rate of a low flow showerhead is 3.8 – 9.5 L/min (Babooram and Hurst, 2010; Blokker et al., 2010; Kappel and Grechenig, 2009; Roberts, 2005; Rosenberg, 2007).

5.2.4 Bath

Baths remain common in some countries and are present in many households. The elderly and children also tend to frequent baths more than showers due to their ease of use (Roberts, 2005; Schleich and Hillenbrand, 2009). Baths may also be used for relaxation purposes in addition to the regular showering for hygiene purposes. Hayasaka et al. (2010) conducted a study which looked at how bathing regularly affects certain health factors, including blood pressure, body mass index, self-rated overall health and sleep quality. The participants who had baths seven or more times a week reported a greater level of health and sleep quality than those who had baths less often. The study by Hayasaka et al. (2010), as well as a study conducted by Deguchi et al., (1996), found that bathing has an overall positive impact on mental health. It was also suggested that baths could be used to help improve sleep for those with insomnia. However, there was no real correlation between the physical health factors studied and frequent bathing. This showed that in terms of mental health, a relaxation bath could be considered necessary especially for meeting higher levels of personal needs.

Bath frequency varies based on many of the aforementioned factors. Bath frequency has been found to vary between an average frequency of 0.044 baths/d (Blokker et al., 2010), presumably when baths are used as a means of relaxation and not for cleaning purposes, and 1 to 2 baths/d for people who use baths for cleaning (Hayasaka et al., 2010).

The volume of a bath is dependent on the size of the bath but also on the height to which the bath is filled. Bath volumes have been found to vary between 80 and 150 L/event (Blokker et al., 2010; Grafton et al., 2011; Hand et al., 2005; Roberts, 2005; Hussien et al., 2016). Jacobs (2004) suggests a practical lower limit of 40 L/event for an adult to bath in and an upper limit of 190 L/event.

5.2.5 Hand washing

Hand washing is vital for good hygiene, with good hand washing regimes being found to cause a 45% reduction in diarrhoea episodes (Adane et al., 2018) and a 16% reduction in respiratory infection (Rabie and Curtis, 2006). Good hand washing practise includes washing hands, at minimum, before preparing food, before feeding a child, before eating food, after defecation, and after cleaning a child who had defecated (Adane et al., 2018). Hand washing frequency may be affected by other factors such as occupation, for example, a medical professional may be required to wash their hands more frequently for health and safety reasons (Sax, 2007). Other miscellaneous activities such as dealing with the ill; washing before religious practices; cleaning glasses or contact lenses; dealing with pets; treating a wound; blowing your nose and sneezing or coughing when ill may also lead to an increased need to wash hands (Centre for Disease Control and Prevention, 2016).

The Centre for Disease Control and Prevention (2016) and the World Health Organisation (2009) recommend that hands are washed in the following manner:

- Wet hands
- Apply soap
- Lather and scrub hands for at least 20 s
- Rinse off soap
- Dry hands.

One of two methods can be followed when performing the aforementioned hand washing procedure. The running water can be left on during the scrubbing process, or the water can be turned off during the scrubbing process. If it is assumed that hand wetting prior to washing and the washing off of the soap after scrubbing takes 5 to 6 s, there will be approximately 20 s difference in water running time (hand washing duration) between the two methods. Standard taps have an average flow rate of about 10 L/min (Rosenberg, 2007; Wong and Mui, 2008), with low flow taps having average flow rates of 6 L/min (Rosenberg, 2007). Consequently, leaving the tap open during hand washing will use an additional 2 to 3 L on top of the base minimum of 0.6 to 1 L of water needed to wash hands.

Washing and drying hands frequently has been found to damage skin, which in turn creates surfaces for bacteria and microbials to grow (Larson, 2001). Therefore, it has been suggested, both for reduction of water use and for skin protection, that people who are required to wash their hands frequently use alcohol-based soaps, such as hand sanitisers. Although hand sanitisers have been found to be effective in killing most germs, they are not effective in killing all germs, some of which may only be dislodged with intense scrubbing (Centre for Disease Control and Prevention, 2016). The effectiveness of hand sanitisers has only been tested on unsoiled hands. Therefore, the effectiveness of hand sanitisers on dirty, greasy hands is questionable as no water, soap and washing action is used which may be required to effectively remove dirt and grease off of hands (Centre for Disease Control and Prevention, 2016; Larson, 2001; Montville et al., 2002; WHO, 2009). Therefore, for frequent hand washers, it is suggested that hand sanitiser are used on unsoiled hands while the proper hand washing procedure be performed otherwise (Centre for Disease Control and Prevention, 2016).

5.2.6 Brushing teeth

The American Dental Association (2019) recommends brushing teeth for two minutes, twice a day, to maintain sound oral hygiene. Twice daily brushing has been found to reduce tooth decay (called caries) in adolescents (Chestnutt et al., 1998). Chestnutt et al. (1998) found that it is better to use a minimal amount of water when rinsing after tooth-brushing; which is found to be best achieved by using the “beaker technique”. The beaker technique is when a beaker or glass is filled with water and used for the tooth-brushing procedure.

5.2.7 Shaving

Shaving is an old hair removal technique which became more popular in the late 20th and early 21st century due to increased ease and convenience (Stilman et al., 2016). Shaving was originally only performed by men who shaved their beards, but in the 1920s shaving started to become the practice of women, first shaving their underarms and later the rest of their bodies (Hansen, 2007). With the increase in popularity of shaving and the desire for hair removal, other means of hair removal became available, including the electric razor, waxing, epilation and laser hair removal. The majority of alternative hair removal techniques do not require water. A study in the UK found that on average 26% of men and 14% of women shave using water, yet in the younger aged working group where participants were more socially active, as much as 41% of men and 22% of women shave using water (Browne et al., 2014). Shaving has been found to be the largest water use activity originating at the bathroom basin, using 0.1 to 7.0 L/event (Matos et al., 2013). However, shaving is not always done in a basin sink, with some people choosing to shave in the shower. Shaving is often performed with shaving cream which means water is required for cleaning of the razor and the shaved body part. When shaving most people will often full up a bathroom basin for use during the shaving process, which accounts for the high, variable volume of water used for shaving.

5.2.8 Clothes washing

Clothes washing, also referred to as laundry, is one of the three highest indoor water users (Beal and Stewart, 2011; DeOreo et al., 2011; Roberts, 2005). Historically clothes washing was done by hand using a washing board and in some regions of the world this is still the case (Pakula and Stamminger, 2010). However, the creation of the automatic washing machine in 1930, lead to a reduced need for hand washing (Speed Queen, 2017). Washing machines are now in around 70 to 100% of urban households (Blokker et al., 2010; Pakula and Stamminger, 2010)

There are two types of automatic washing machines, namely the top-end loader (or vertical axis) and the front-end loader (or horizontal axis) washing machine. In terms of water-saving abilities horizontal axis machines are, on average, more efficient as they only have water filling the bottom of the machine while vertical axis machines typically fill the whole machine up with water before washing. Horizontal axis machines have been found to use approximately half the amount of water that vertical axis machine use (Botha et al., 2018). Most modern horizontal axis machines further reduce water usage by using sensors to determine how large a load is and in turn only supply the required amount of water for that load size. Consequently, front-end loaders have shown an upward trend in popularity increasing from 13% to 22% of sales from 2005 to 2007 in Australia, with some areas reaching 50% of sales being front-end loaders (Pakula and Stamminger, 2010; Iglehart et al., 2011). Botha et al. (2018) found sales of front-end loaders in South Africa to be 63%.

Intuitively, the number of wash cycles per household will increase with an increase in household size, however, the number of washes per person will decrease with an increase in household size. Washing machine frequency varies between 111 cycles/year for a single-person household to between 211 and 312 cycles/year for a four-person household (Stamminger and Goerdeler, 2007; De Almeida et al., 2006; Iglehart et al., 2011; Botha et al., 2018).

Water use by washing machines will be affected by the type of washing machine as well as user behaviour, therefore, different areas throughout the world will show different water use trends. For example, European washing machine water use tends to be less than other studied areas such as Australia and America, mostly due to the fact that the majority of European washing machines are horizontal axis machines. Pakula and Stamminger (2010) conducted a study on around 590 million washing machines in 38 countries, giving an overall idea of washing machine behaviour. It was found that washing machines use between 5% and 19% of household water; depending on water use per wash cycle, frequency of washing as well as overall household water use. Washing machine water use per cycle varies based on the type of washing machine and the wash setting used. Typical water use values range between 60 and 145 L/cycle in older larger washing machines with values as low as 50 L/cycle for small water efficient washing machines (Botha et al., 2018). A review of international online retail websites was done to determine the percentage of various washing machine types that are sold in different countries. A summary of the percentages of washing machine types sold in each region is given in Table 5.2. The percentage values were calculated by dividing the total number of a type of washing machine sold by the company, as reported online, by the total washing machines sold by the company.

Washing machines often get a build-up of detergent and bacteria and sometimes mould. Therefore, monthly empty wash cycles are recommended to clean out any build up in the washing machine. A full hot wash cycle with an extra rinse cycle is recommended for effective cleaning (Leverette, 2019).

Table 5.2: Distribution of different washing machines sold by retail outlets

Country	Outlet/Type	Washing Machine Volume (L)	% sold	Reference
United Kingdom	Indesit front loader	30 – 39	15	Indesit (2019)
		40 – 49	15	
		50 – 59	69	
		> 60	0	
	LG front loader	30 – 39	0	LG (2019)
		40 – 49	81	
		50 – 59	19	
		> 60	0	
	Appliances direct front loader	30 – 39	40	Appliances Direct, (2019)
		40 – 49	60	
		50 – 59	0	
		> 60	0	
	Bosch - combo washer dryer	50 – 89	17	Bosch (2019)
		90 – 110	50	
		111 – 125	33	
		> 125	0	
	Hotpoint	30 – 39	0	Hotspot (2019)
		40 – 49	50	
		50 – 59	50	
		> 60	0	
United States of America	Energy Star front loader	20 – 29	24	Energy Star (2019)
		30 – 39	1	
		40 – 49	22	
		50 – 59	28	
	Energy Star top loader	50 – 89	99	Energy Star (2019)
		90 – 110	1	
		111 – 125	0	
		> 125	0	
Canada	Energy Star - top loader	50 – 89	97	Energy Star (2019)
		90 – 110	3	
		111 – 125	0	
		> 125	0	
	Energy Star front Loader	20 – 29	12	Energy Star (2019)
		30 – 39	18	
		40 – 49	26	
		50 – 59	40	
Asia	Hitachi combo washer dryer	50 – 89	50	Hitachi (2019)
		90 – 110	0	
		111 – 125	50	
		> 125	0	

Country	Outlet/Type	Washing Machine Volume (L)	% sold	Reference
Asia	Hitachi Top Loader	50 – 89	7	Hitachi (2019)
		90 – 110	21	
		111 – 125	14	
		> 125	62	
	Hitachi Front loader	30 – 39	0	Hitachi (2019)
		40 – 49	100	
		50 – 59	0	
		> 60	0	
Australia	Harvey Norman and Appliances online front loader	30 – 39	0	Harvey Norman (2019) Appliances Online, (2019)
		40 – 49	0	
		50 – 59	6	
		> 60	94	
	Harvey Norman and Appliances online top loader	50 – 89	54	Harvey Norman (2019) Appliances Online (2019)
		90 – 110	16	
		111 – 125	16	
		> 125	14	
South Africa	Bosch Siemens AEG Defy Whirlpool SMEG Panasonic	30 – 39	0	Botha et al. (2018)
		40 – 49	5	
		50 – 59	82	
		> 60	13	

5.2.9 Cooking

Water is a vital component of cooking in many instances. Adequate clean water for cooking has been found to play an important role in reducing disease and diarrhoea, especially in children in developing countries (Herbert, 1985). The volume of water required for cooking varies significantly from region to region and from day to day depending on the type of meal being prepared, the cuisine of the country and the role of the water in the food preparation. Minimum suggested water requirements in literature range from 1.5 L/c/d (Thompson et al., 2001) to 10.0 L/c/d – which included water for all activities relating to cooking (Gleick, 1996). WHO derived the minimum water requires for cooking by making a basic assumption to allow for the preparation of a grain, such as rice or pasta, as a basic food source. The traditional food pyramid suggests 6 to 11 servings of grains with a serving being approximately 100 g. Therefore, to prepare the grain using the absorption method, 1.6 L/c/d would be required for 600 g of grain (Willett and Stampfer, 2003; WHO, 2003). More water may be needed for other food preparation, however, it is safe to assume a minimum water requirement of 1.6 L/c/d.

5.2.10 Dishwashing – automatic

The dishwasher was invented in the mid-1800s, yet only became domestically popular in the 1950s (Gizmo Highway, 2011). However, approximately 34% to 63% of urban households still do not own a dishwasher, choosing to only wash dishes by hand (Berkholz et al., 2010; Blokker, 2006; Gleick et al., 2003; Vinogradova et al., 2012). Dishwashers have a relatively small contribution to indoor water use, contributing to between 3% (Matos et al., 2013) and 10% (Sadr et al., 2016). Modern dishwashers have become extremely water efficient, with most dishwashers requiring between 6.5 and 13.5 L/load for a regular cycle (Berkholz et al., 2010). Furthermore, it has been found that dishwashers use 50% to 80% less water than washing dishes by hand (Berkholz et al., 2010; Richter, 2011). Additionally, dishwashers are both energy and time efficient (Berkholz et al., 2010). However, dishwasher water efficiency lies predominantly with consumer behaviour, as pre-rinsing and soaking of dishes, as well as the dishwasher programme chosen, can reduce the water efficiency of dishwashers significantly (Richter, 2010).

Worldwide, there are many brands of dishwashers, with different water requirements ranging from 6.5 to 15.0 L/load. A review of international online retail websites was done to determine the percentage of various dishwasher types sold in different countries, as done previously with toilets and washing machines. A summary of the percentages of dishwasher types sold in each region is given in Table 5.3.

Even though dishwashers have a pre-rinse function, between 16.8% (Richter, 2011) and 50% (Vinogradova et al., 2012) of dishwasher owners pre-rinse their dishes before they put them into the dishwasher. Pre-rinsing dishes by hand uses significantly more water than using the pre-rinse function of the dishwasher itself. Studies have shown that pre-rinsing dishes by hand uses, on average, between 11.0 and 20.0 L/load while a normal pre-rinse function on a dishwasher uses only 5.0 L/load (Richter, 2011).

The frequency of dishwasher use varies depending on household size and the amount of cooking done at home. However, literature suggests a dishwasher use frequency of 0.3 events/d for a single-person household (Roberts, 2005) to between 0.6 and 1.0 events/d for a larger four-person household (Berkholz et al., 2010; Roberts, 2005).

Dishwashers collect food remains and bacteria in them over time. Therefore, a monthly wash and rinse cycle are recommended to keep the dishwasher clean (Leverette, 2019). The volume of the rinse cycle will depend on the dishwasher brand and cycle chosen.

Table 5.3: Distribution of different water consuming dishwashers sold by retail outlets

Country	Outlet	Dishwasher Wash Volume (L)	% sold	Reference
SA	Tafelberg Furnishers	6.5 – 9.0	16	Tafelberg Furnishers (2019)
		9.5 – 11.0	42	
		11.5 – 13.5	26	
		14.0 – 15.0	16	
	Hirsch	6.5 – 9.0	25	Hirsch's (2019)
		9.5 – 11.0	43	
		11.5 – 13.5	25	
		14.0 – 15.0	7	
USA	Energy Star	6.5 – 9.0	6	Energy Star (2019)
		9.5 – 11.0	29	
		11.5 – 13.5	65	
		14.0 – 15.0	0	
Canada	Energy Star	6.5 – 9.0	6	Energy Star (2019)
		9.5 – 11.0	28	
		11.5 – 13.5	66	
		14.0 – 15.0	0	
Australia	Harvey Norman and Appliances online	6.5 – 9.0	12	Appliances Online (2019) Harvey Norman (2019)
		9.5 – 11.0	14	
		11.5 – 13.5	62	
		14.0 – 15.0	12	
United Kingdom	Appliances Direct	6.5 – 9.0	22	Appliances Direct (2019)
		9.5 – 11.0	52	
		11.5 – 13.5	26	
		14.0 – 15.0	0	
United Kingdom	Indesit	6.5 – 9.0	8	Indesit (2019)
		9.5 – 11.0	42	
		11.5 – 13.5	50	
		14.0 – 15.0	0	
United Kingdom	Whirlpool	6.5 – 9.0	38	Whirlpool (2019)
		9.5 – 11.0	29	
		11.5 – 13.5	33	
		14.0 – 15.0	0	
Asia	Electrolux	6.5 – 9.0	11	Electrolux (2019)
		9.5 – 11.0	89	
		11.5 – 13.5	0	
		14.0 – 15.0	0	

5.2.11 Dishwashing – by hand

Hand washing dishes has been found to use significantly more water than modern water efficient dishwashers (Berkholz et al., 2010; Richter, 2011). Three methods are commonly followed when hand washing dishes, these are filling up a sink or bucket with water and washing the dishes in the water, washing the dishes under running water from the tap and a combination of the previous two methods, where the dishes are washed in the filled up water and then the soap suds are rinsed off under running water (Richter, 2010). Pre-rinsing of soiled dished can also be done before hand washing dishes. Water use varies significantly for hand washing dishes due to the variability in the volume of dishes, the method of cleaning, the height to which the sink is filled with water, how dirty the dishes are and the performance of pre-rinsing. However, it can be assumed for a single-person household, a sink of water filled with approximately 5 to 10 L of water and approximately 2 L for rinsing is adequate for each dish washing event. These assumptions are comparable to the results obtained by Berkholz et al. (2010) when determining per capita water use for hand washing dishes, which equated to 17.6 L/c/d for an average household size of 2.5 PPH.

Some dishwasher owners will occasionally wash dishes by hand for some of the following reasons: the dishes are too big or oddly shaped to fit in the dishwasher; the dishes are considered too expensive, delicate or important to go in the dishwasher; the dish is needed immediately; there are not enough dishes to justify using a dishwasher or dishes are too soiled to be clean effectively (Richter, 2010). The frequency of hand washing dishes, as specified by Berkholz et al. (2010), differs between dishwasher owners and non-dishwasher owners as shown in Table 5.4.

Table 5.4: Hand washing dishes frequency (Berkholz et al. 2010)

Frequency of hand washing dishes (events/week)	Percentage of non-dishwasher owners	Percentage of dishwasher owners
17.5	56.0	25.0
7.0	32.0	43.0
4.0	2.0	5.0
2.5	5.0	9.0
1.0	1.0	5.0
0.5	1.0	9.0
0.0	0.0	2.0

5.2.12 Cleaning the house

Kitchen and bathroom hygiene is significantly associated with diarrhoea, hence the need for frequent cleaning of a house (Baltazar et al., 1993). A typical German house use 7% of water for household cleaning, washing cars and gardening (Schleich and Hillenbrand, 2009). Water used to clean the floors in a house is typically dispensed into a bucket and used from there. Sadr et al. (2016) found that water used for washing floors averaged 12 L/c/d for both apartments and detached houses, demonstrating that the size of the house does not affect the water used for washing floors as a bucket will be filled regardless. Water use for household cleaning generally ranges between 11 and 16 L/c/d (Hussien et al., 2016; Sadr et al., 2016).

Kitchen cleanliness is important for health and therefore, it is of the utmost importance to clean down kitchen counters after any food preparation has taken place (Scott, 1999).

5.2.13 Indoor plants

Bringing plants from the outdoors inside dates to as far back as the 3rd century BC in Egypt yet became more popular in the second half of the 20th century with the increased ease and reduced cost of tropical plant production and transportation (Bringslimark et al., 2009). The presence of indoor gardening has been found to have a significant influence on the overall health and happiness of members of a nursing home (Tse, 2010) and has been found to reduce stress in the workplace (Chang and Chen, 2005; Largo-Woght et al., 2011). Additionally, indoor plants have been found to increase the local air quality of the area they are in (Tarran et al., 2007). There is currently no available literature on the penetration rate and water use of indoor plants.

5.3 Water requirements for water use activities - outdoor

5.3.1 Irrigation

Urban gardens in detached houses are becoming more common with up to 91% of people in a study in East England having an outdoor space, of which 62% are gardens needing to be watered (Pullinger et al., 2013) and 68% of people in a study in Perth, Australia using water for irrigation (Water Corporation, 2010). The act of gardening has been found to improve mental health and provide social and economic benefits (Syme et al., 2004). In modern times, gardening is often seen as a means of expressing oneself and allows for space where family and friends can connect to nature. Gardens can be an extension of the home, often surrounding patios or paved areas where outside entertainment facilities are contained. The way a garden is presented is often seen as a socio-economic symbol showcasing the household, with a larger, better landscaped garden being a sign of wealth and status (Askew and McGuirk, 2004; Domene et al., 2005). Gardens are also used for practical means such as growing vegetables to be used for eating (Pullinger et al., 2013). Therefore, an argument can be made with regards to the necessity of a garden for the overwhelming psychological and social benefits that a garden brings.

Irrigation is the largest contributor to outdoor water use (Loh and Coghlan, 2003; Syme et al., 2004), as well as overall water use, amounting to approximately 30% to 50% of overall water use (Garcia et al., 2014; Mini et al., 2014; Salvador et al., 2011). The high outdoor water use for irrigation is most likely due to the high prevalence of gardens and lawns in households with outdoor spaces, whereas other outdoor water uses, such as filling swimming pools and washing cars is much more variable amongst different households. Consequently, irrigation is the first target when water authorities need to reduce water use, as water for irrigation is non-essential and is a large water consumer (Ferrara, 2008). Restrictions placed on irrigation have been found to reduce per capita outdoor water use by 18% to 56% in some cities in Colorado, USA (Kenney et al., 2004).

Irrigation is often split into lawn and garden irrigation, although, the same factors generally apply to both when determining water requirements. The water requirements for irrigation depend on the size of the garden or lawn, the type of landscaping, the efficiency of the irrigation system and the climate. It has been argued that the type of plants and/or lawn used and the design of the landscaping is more significant than the size of a garden when it comes to water use (Hoff and Wolf, 2014). Irrigation has been found to be seasonal with a higher irrigation frequency in the warmer summer months and a lower frequency in the winter months, resulting in outdoor and/or irrigation use being calculated by subtracting the winter water use from the summer water use (Romero and Dukes, 2014; Lambert, 2018; Syme et al., 2004). Contrarily, Johnson and Belitz (2012) found that irrigation does not significantly fluctuate seasonally. This may be due to automatic irrigation system times not being changed during winter or due to areas having summer rainfall and therefore requiring less irrigation in summer and requiring some irrigation in winter to keep the evergreen plants and lawn alive. However, it seems more common that irrigation varies seasonally, especially in climates with varied summer and winter temperatures. The irrigation season typically ranges between 20 and 40 weeks depending on the local climate and the amount of rainfall that season (Roberts, 2005; Rosenberg, 2007).

Climate plays a significant role in irrigation. A common method to determine the exact irrigation needs of a plant is to determine the evapotranspiration of the plant. Evapotranspiration takes into consideration a vast number of factors including air temperature, wind speed, saturation vapour pressure and actual vapour pressure, which are all climate dependent (Makwiza et al., 2015). Even though evapotranspiration along with antecedent soil conditions can be used to determine the water requirements for irrigation, most homeowners will make use of an irrigation method that does not take these factors into account, resulting in inefficient irrigation. Temperature affects irrigation patterns, with warmer temperatures generally resulting in larger irrigation volumes (Rathnayaka et al., 2017).

There are many types of irrigation methods, some common methods include the manual bucket, hand-held hose, a manual sprinkler system, an automatic sprinkler system and drip irrigation. Each irrigation system has a different water requirement, with the drip or smart irrigation systems and the manual bucket generally using the least amount of water and the manual and automatic sprinklers using the most amount of water (Rathnayaka et al., 2014). Irrigation effectiveness relates to how effective the lawn or garden is watered with regards to lost water to impermeable surfaces and over or under watering of the irrigable surfaces. Most homeowners do not irrigate effectively, with about 60% over-irrigating and only 6% under-irrigating, while only 34% irrigating sufficiently (Salvador et al., 2011).

Since irrigation is site-specific, due to the variety of plants and lawn types being used for landscaping, it is difficult to make a reliable generalised estimation of water use for irrigation (Gleick et al., 2003). Garden and lawn irrigation areas have been mapped out fairly accurately, in some countries, using GIS; which means a site-specific irrigation water use can be estimated based on the irrigable garden and lawn area and the effective rainfall in the area (Hoff and Wolf, 2014). Irrigation frequency ranges from 1 to 7 times a week, averaging 4 times a week (Roberts, 2005). Irrigation volume is dependent on the duration, which can range between 300 and 7200 s depending on the type of irrigation method and flow rate which generally averages 0.25 L/s, giving a volume range of 75 to 1800 L/event (Roberts, 2005).

Methods to reduce water use for lawn and garden irrigation include xeriscaping which involves planting indigenous low water consuming plants; installing a smart irrigation controller which irrigates based on the moisture of the soil and thus only irrigates when necessary; installing fake grass and using stress irrigation. Water efficient irrigation systems have been found to reduce water use by as much as 31% in low-density households and up to 10% in high-density households (Ferrara, 2008). However, some studies have found that water-smart irrigation systems are not effective in reducing water use as they are often programmed or used incorrectly, or are installed in larger gardens with high water requiring plants (Cubino et al., 2014; Domene et al., 2005; Syme et al., 2004; Wentz and Gober, 2007).

Installing rainwater tanks to collect rainwater for outdoor use such as garden irrigation has been found to be an effective means of reducing the use of potable water (Willis et al., 2013). The quantity of water used for irrigation does not change with the installation of rainwater tanks, however, the demand on water authorities to provide water for irrigation, which does not require potable standard water, is reduced.

5.3.2 Swimming pool

Swimming pools have become a standard feature in a large proportion of middle to high-income areas in warm countries, being used as a place for leisure activities and as a symbol of status in western countries (Vidal et al., 2011). There has been an increase in the popularity of home swimming pools due to an increase in family income and the privatisation of the previously public act of going to a public swimming pool (Loh and Coghlan, 2003; Vidal et al., 2011). Water used for swimming pools makes up only a small proportion of outdoor water use, at about 8% to 15% (Hoff and Wolf, 2014; Loh and Coghlan, 2003). However, households with swimming pools have been found to have an outdoor water use of up to two times more than that of households without a swimming pool, when all other factors are the same (Cubino et al., 2014; Mayer et al., 1999; Wentz et al., 2014). This phenomenon is most likely due to pride being taken in the outdoor space as more time is spent outdoors as well as the fact that households with swimming pools are more likely to be in warmer climates, requiring more frequent irrigation of gardens and lawns. The water required for a pool depends on several factors, including the pool size, the climate of the area, the presence or absence of a pool cover, the frequency of and volume used for backwashing and the presence of leaks.

A penetration rate of 40% for permanent swimming pools and 4% for temporary above the ground swimming pools was found in a study of three cities in Spain (Llausàs et al., 2018). The penetration rate is in line with the penetration rate of 35% found for swimming pools of middle to high-income households in Cape Town, South African (Fisher-Jeffes et al., 2014), yet higher than the penetration rate of 10% found in Melbourne, Australia and East Bay, USA (Rathnayaka et al., 2014; Water Resources Engineering, 2002). Pool size varies in different locations, mostly due to the difference in plot sizes. On average, a standard pool surface area is between 30 to 40 m^2 in Europe (Llausàs et al., 2018; Morote et al., 2017; Vidal et al., 2011) and slightly larger at an average of 50 m^2 in the USA (Gross and Lee, 2013). The pool size and climate will affect the evaporation off the pool surface which will dictate the frequency of refilling. If a pool has a pool cover then the evaporation of the pool during the periods when the pool cover is in use will be zero, which means the only water requirements for the pool will be that of the backwash volume and any leaks causing water loss (Jacobs and Haarhoff, 2004b). The presence of pool covers has not been studied extensively in literature, however, Llausàs et al. (2018) found 3% to 13%, depending on location, of the Spanish population use pool covers. Jacobs and Haarhoff (2004b) suggest that most pools are covered fully in winter months, 50% of the time in the transitional months of May and September and are not covered in the summer months due to the frequency of use of the swimming pool.

Besides leaks, which are a nonessential water requirement for swimming pools, the two water use parameters are pool evaporation and water used for backwashing and filtering of the pool. Evaporation is affected by the climate of the area and the surface area of the swimming pool. Water required to replenish evaporation is calculated in the same manner as that for irrigation. The method described by Jacobs and Haarhoff (2004b) to determine evaporation for garden irrigation, which was also used by Fisher-Jeffes et al. (2014), is used to determine water requirements for pool evaporation. An alternative method for determining pool evaporation using the more complicated Penman formula is described by Hoff and Wolf (2014). Water used for backwashing and filtering is dependent on backwash volume and frequency. Backwash volume has been found to stay constant for every backwash once a routine has been put in place, with the volume varying depending on the size of the pool and the time which the backwash is run for. Average backwash volumes range between 100 to 600 L/event (Fisher-Jeffes et al., 2014; Jacobs and Haarhoff, 2004b). Frequency of backwashing is, once again, a consumer preference with literature being quite varied on the normal average frequency. Jacobs and Haarhoff (2004b) suggest a frequency of between 0.36 events/month and 1 events/month with an average frequency of 0.72 events/month, yet Fisher-Jeffes et al., 2014 suggests a frequency of 1 events/month is common with some people backwashing as frequently as 4 events/month. The water use for backwashing a swimming pool, calculated by multiplying the volume of backwashing by the frequency, is approximately 60 to 120 L/d which is comparable to the 57 L/d found by Vidal et al. (2011). The water use volumes found in the aforementioned studies are site specific which means the climate and pool sizes are taken into consideration. A more generalised formula for the water requirements for swimming pools without leaks, as used Fisher-Jeffes et al. (2014), can be used for any location.

Water is also lost through leaks in a pool. However, not all swimming pools leak, and should a swimming pool have a leak, the volume of the leaks is quite often proportionally much greater than the other water requirements of the swimming pool. Therefore, Jacobs (2004) suggests including swimming pool leaks with all other leaks and not with swimming pool water use.

5.3.3 Car washing

Car washing is a necessary activity for the maintenance of a car. Historically cars were mostly washed at home with a bucket or hosepipe, but in recent times automatic car washes have become more popular (Janik and Kupiec, 2007). Home car washes generally consist of the use of water from a bucket and/or a garden hose. A study by Smith and Shilley (2009) found in the City of Federal Way in the United States, that 38% of people wash their car in the driveway. Whereas the International Carwash Association (ICA, 2017) found that in the United States, 16% of people wash their cars at home and 40% wash their cars approximately 50% at home and 50% at a professional carwash. Yet in Europe, only 10% of people wash their cars only at home and 16% at home and a professional car wash. The remainder of car owners wash their cars exclusively at a professional carwash. The frequency of home car washes, as found by Smith and Shilley (2009), and professional car washes, as found by the International Carwash Association (ICA, 2017), is summarised in Table 5.5. The weighted average of the frequencies in Table 5.5 is comparable to the car wash frequency found by Hussien et al. (2016). The volume of water used for car washing is dependent on the car wash mechanism used. Smith and Shilley (2009) suggest home car washing uses 76 L/wash, while Janik and Kupiec (2007) suggest a value as high as 440 L/wash, however, the value is dependent on whether a bucket and/or a hosepipe is used and how many buckets are used or how long the hosepipe is on. It could be argued that one bucket of water is required to wash the car and another to rinse the car. A bucket is between 11 L and 26 L (Rosenberg, 2007) meaning a home car wash could use as little as 22 L to 52 L. It is generally perceived by the public that professional car washes use less water and are better for the environment (ICA, 2017). The different types of professional car washes include stand-alone self-service, in-bay automatic, conveyor, touchless and hybrid car washes. The water requirements for these professional car washes vary from 61 L/wash for self-service car washes to 270 L/wash for touchless automatic car washes (Janik and Kupiec, 2007). Changes in climate based on the region has been found to have little effect on the water use of professional car washes, most likely due to the car wash volumes being regular regardless of the ambient temperature and humidity (Brown, 2002).

Table 5.5: Distribution of car wash

Car Wash Frequency	**Percentage of home car washes** (Smith and Shilley, 2009)	**Percentage of professional car washes - Europe** (ICA, 2017)	**Percentage of professional car washes - USA** (ICA, 2017)
Once a year	3	5	4
Every six months	13	17	12
Every three to four months	14	33	32
Once a month	32	30	26
A few times a month	27	13	21
≥ Once a week	11	3	6

Water recycling systems can reduce water use, thus reducing the environmental impact of the car wash as well as water costs. However, in countries that use salt on their roads, a reverse osmosis process is often required to extract the salt from the recycled water prior to reuse, which could impose an increase in the cost of running the car wash (Janik and Kupiec, 2007). The retrofitting of water recycling systems in older car washes will require an initial capital outlay which may not be feasible for smaller car wash companies.

5.4 Water requirements for water use activities - miscellaneous

5.4.1 Pets

Keeping animals as pets for personal enjoyment and companionship dates to the 18^{th} century (Grier, 2010). In modern society, pets are kept in over 50% of households internationally (Growth from Knowlege, 2016). All domestic animals require care to some degree, with the most basic care being the provision of food, water and basic hygiene. Furthermore, washing hands before and after handling pets is always recommended (Gee et al., 2017).

It is recommended that small animals such as hamsters, rats and guinea pigs are kept in cages with at least one companion as they are social animals. Freshwater should always be available through a side-mounted dispenser (Gee et al., 2017). In order to maintain the freshness of the water in the dispenser, the water should be replaced every day, with a typical dispenser holding between 100 and 250 mL (Pet World, 2019). The cage should also be cleaned at least once a week, with spot cleans being done when necessary (Gee et al., 2017). Cleaning of a cage will require a bucket of water of approximately 6 to 11 L (Rosenberg, 2007).

Household fish are generally kept in three different size reservoirs, namely an indoor fishbowl, a larger fish tank and an outdoor fishpond. Fishbowl sizes range from about 2 to 10 L, while larger fish tanks range from about 10 to 100 L (Aquarium Universe, 2019). A complete water change for small fishbowls is recommended, while a 20% weekly water change is the minimum requirement for indoor fish tanks, yet these requirements vary for different environments depending on the water conditions (Gee et al., 2017). It is recommended that turtles are treated in the same manner as fish in an indoor fish tank with the same cleaning procedures being required for the turtle tank (McLeod, 2019). Outdoor ponds require larger amounts of maintenance with seasonal and routine maintenance being required. Seasonal maintenance, which occurs biannually, requires the pond to be almost entirely drained and cleaned. While routine maintenance is usually performed fortnightly or weekly with a small siphoning off of water being required occasionally to maintain freshwater (South African Home Owner, 2012). Outdoor fish ponds generally range between 850 and 10 000 L (River Rock Designs, 2019), resulting in a fortnightly or weekly water requirement of around 85 to 1000 L for routine maintenance, if 10% of the pond size is replaced weekly.

There are over 300 different breeds of dogs in the world ranging from dogs as small as 2 kg to dogs as large as 150 kg. However, the most common breeds of dogs are generally between 15 and 45 kg (American Kennel Club Staff, 2018). Due to the varying size and types of dogs, the water requirements for dogs vary significantly depending on the dog. However, all dogs require drinking water for hydration and water for cleaning periodically. Dogs water bowls need to be filled twice daily, with bowl size ranging from 0.25 to 3.7 L depending on the size of the dog (petheaven, 2019). Dogs also require washing, which should be done anywhere from weekly for problem or outdoor dogs with long hair to once every three months (Lotz, 2018). It is recommended to wash a dog in a tub or bath to contain the washing water. Smaller dogs will require a smaller tub using approximately 5 to 10 L per wash while medium size dogs will require a larger tub using approximately 20 to 30 L per wash. Large dogs may use up to 50 to 75 L per wash.

Cats are smaller animals, averaging only 3.5 to 4.5 kg. Cats require water for drinking and water to clean their litter boxes. Cats need a water bowl which should be refilled twice a day, with cat water bowl sizes being approximately 200 to 250 mL (Pet World, 2019). It is suggested to clean out litter boxes between once a week and once every two weeks, which involves cleaning out the litter and washing the litter box thoroughly (The Human Society of The United States, 2019).

Reptiles, such as snakes and lizards, are becoming common domestic pets. They are generally low water consuming animals. All reptiles always require a water bowl with clean water for drinking to be present in their cage. Some snakes will soak in their water bowls so it is recommended that the water bowl be just bigger than the snake so that they do not drown (Cornett, 2019; McLeod, 2019). Smaller reptiles will require a small drinking bowl similar to that of cat bowl while snake water bowls will vary based on the size of the snakes. Common snakes kept as pets are Boidae, Pythonidae and Colubridae (Kruzer, 2019). Common domestic snakes range in size from 0.5 m to 6 m, however larger snakes, such as the Burmese Python, cannot soak in their water bowls and will only need a drinking water bowl. Therefore, dog water bowls sizes are appropriate for snakes, with the smaller 1 L bowls being used for the smaller snakes and the larger 3.7 L bowls being appropriate for larger snakes. Snake water bowls generally need to be replenished once a week or when the snake has urinated or defecated in or around the water bowl (Cornett, 2019). Additionally, reptile enclosures need to be cleaned. Weekly cleanings of a wipe down with a thorough monthly cleaning are recommended (Animal City, 2016). A weekly wipe down will require a clean wet cloth only needing 0.5 to 2 L of water while monthly cleanings will require more thorough cleaning meaning a bucket of water may be necessary, resulting in a 5 to 10 L water requirement depending on the size of the reptile enclosure.

Birds are another common domestic pet, with owners of only a few smaller birds often housing them in small cages while large numbers of birds or larger birds are housed in aviaries. Birds require water for drinking and water is needed to clean their cage. It is recommended that clean water is available to birds at all time with water bowls being cleaned out twice daily (PETA, 2013). Additionally, a birdbath is recommended to promote preening (PETA, 2013). Water bowls range from 0.15 L for smaller birds such as Budgies to 0.9 L for larger birds such as Macaws (Pet World, 2019). Birdbaths are generally the same size as that of the water bowls. Larger birds require a weekly cage cleaning while smaller birds only requiring their cages to be cleaned once a month (Mariposa Veterinary Wellness Center, 2019). Monthly or weekly cage cleanings involve cleaning the cage with soap and water and cleaning the perches and toys in the cage, which is often most easily done in the dishwasher (Mariposa Veterinary Wellness Center, 2019). Bird aviaries are much larger and usually house large birds or large numbers of smaller birds. Thorough cleaning of an aviary should be done weekly with a bucket of water, while daily cleaning of food and water containers and replacement of water should be done daily (Trader, 2018). Aviary water dispensers range in volume from 1 to 12 L to compensate for the larger water needs of the birds in the aviary (Miscola, 2019).

A number of studies have been conducted to determine the number of various types of pets in different countries. The most notable being a 2016 study of over 27 000 people in 22 countries worldwide. A summary of the percentage of ownership of different pets from different sources is presented in Table 5.6.

Table 5.6: Summary of percentage of pet ownership worldwide

Pet Type	**Percentage Ownership per Pet**			
	Worldwide (Growth from Knowlege, 2016)	**US** (Insurance Information Institute, 2018)	**Worldwide** (Statistica, 2016)	**UK** (PFMA, 2017)
Dog	33.0	41.0	34.0	24.0
Cat	23.0	28.0	27.0	17.0
Fish	12.0	10.0	11.0	13.0 (5 outdoor)
Bird	6.0	5.0	7.0	5.0 (outdoor)
Reptile	-	3.0	-	1.5
Small animals	-	5.0	-	6.0
Other	6.0	2.0	-	-

5.4.2 Leakages and real losses

Water leakage can occur both in the distribution pipes to houses as well as in post meter distribution pipe systems leading to and within a house. Leakage in a house can account for anywhere from 2% (Athuraliya et al., 2012) to 20% (Heinrich, 2009; Water Corporation, 2010) of total water use. Approximately 17% of households have significant leakages (Water Corporation, 2010). Leakages can happen in many areas of the house, including, but not limited to, toilets, taps, swimming pools, pipes and geysers. Leak reduction in a bulk distribution network is often achieved through pump control, throttled line valves, automatic control valves, and pressure management (Walski et al., 2006). Post meter leak reduction is often achieved through the installation of smart meter technology, which has been developed to detect leakages more efficiently and effectively (Britton et al., 2013). Leaks are detected by measuring a baseline flow, called a minimum night flow (MNF) at predetermined time intervals – experienced at times of minimum water use – and detecting when the water use at those times is greater than the MNF (Britton et al., 2013). A large amount of research is available on leakages in distribution networks, however, there is limited research available on leakages within a house (Britton et al., 2008). Post meter leakage volumes generally range anywhere from 15 to 82 L/hh/d depending on the site of the leak, the number of leaks and the pressure at the site of the leak (Liu et al., 2016; Mayer et al., 1999; Water Corporation, 2010).

5.4.3 Miscellaneous water use

Miscellaneous water use activities are infrequent water use activities such as cleaning of the fridge or freezer as well as water used in emergencies such as water used when sick or during a small fire in the home. Other miscellaneous water use activities include activities that indirectly require water such as extra water used when caring for the sick or old, or water used when handling contact lenses or glasses. A thorough cleaning of the fridge with a solution of dishwashing soap and 1 L of water and then a rinse is recommended every three months (Leverette, 2019).

Approximately 61% of the population wears glasses or contact lenses, with 57% of people wearing glasses and 12% of people wearing contact lenses – the sum of glasses and contact lens wearers is greater than the total, as some people report to wear both contact lenses and glasses in a day (CBS, 2013). It is recommended that before inserting and removing contact lenses hands are washed thoroughly in order to remove any potential microbials that may transfer onto the contact lenses, causing problems in the eye (Radford et al., 2009). Cleaning of eyeglasses is recommended daily by first washing hands and then washing the glasses with soap and water (Heiting, 2019).

It is recommended that you clean your house windows every three months, however, some residents clean their windows more frequently and others only clean them once every four months (Rosengren, 2014). There is no published data on how much water is required for washing windows, however, it can be assumed that water from a bucket is used. Therefore, a minimum of around 6 L/event would be expected for washing windows.

6 LCD Model Development

6.1 Overview of model development

This chapter deals with the development of the litre per capita per day (LCD) model. As part of the model development, attention was given to each of the 135 model input parameter. Each water use activity was described by various model inputs, or independent variables, which are also discussed in this chapter. The first step of the model development focused on the ultimate consumption lifestyle level.

A summary of the equations used to determine the water use for each water use activity is given in Table 6.1. The water use activities that made use of the same equation format were grouped together. Thereafter, all other water use activities that had separate equations were listed in the table. Section 6.2 to section 6.4 provide a detailed description of the distributions and values chosen to describe each parameter in the equations used to determine the water use for each water use activity. Parameter values were selected from the knowledge review (Chapter 5). All references used to determine the parameter values are summarised in Appendix C. The water use activities were categorised as indoor, outdoor or miscellaneous activities. A secondary classification was introduced to describe the location within the house where the activity takes place. For example, activities that typically occur within the bathroom were grouped together.

6.2 Indoor water use

6.2.1 Drinking

Based on a thorough review of all the literature sources presented in Chapter 5, it was considered appropriate to use a lognormal distribution with a mean of 2.0 L/c/d and a standard deviation of 0.75 L/c/d to model drinking water volume. Drinking water volume includes any consumed liquid with water as a base – also hot brewed beverages.

Table 6.1: Summary of equations used to calculate water use for water use activities

Water Use Activity	Component	Equation	Discussion Section
Brushing teeth	Indoor	$WU = F\ V$ Where: WU = water use (L/c/d) F = frequency (events/c/d) V = volume of event (L)	6.2.6
Cleaning kitchen counters	Indoor		6.2.12
Dishwasher cleaning	Miscellaneous		6.4.3
Fridge cleaning	Miscellaneous		6.4.3
Other miscellaneous water uses	Miscellaneous		6.4.3
Washing machine cleaning	Miscellaneous		6.4.3
Indoor plants	Indoor	$WU = Occur\ V$ Where: WU = water use (L/c/d) V = volume of event (L) Occur is a binomial variable (0,1) prescribing the occurrence (1) of the activity	6.2.14
Leakages and real losses	Miscellaneous		6.4.2
Cleaning the house	Indoor	$WU = \mathrm{F}\ \mathrm{V_{bucket}}\ \mathrm{No.\,of\,buckets}$ Where: WU = water use (L/c/d) V_{bucket} = volume of the bucket used (L) No. of buckets = number of buckets used for the activity	6.2.13
Window washing	Miscellaneous		6.4.3

<table>
<tr><td>Clothes washing</td><td>Indoor</td><td rowspan="3">$$\mathrm{WU} = \mathrm{Occur}\,(\mathrm{F}\,\mathrm{V})$$
Where:
WU = water use (L/c/d)
F = frequency (events/c/d)
V = volume of event (L)
Occur is a binomial variable (0,1) prescribing the occurrence (1) of the activity. In the case of the clothes washer, Occur is a binomial variable (0, 1) prescribing the use of a top-end loader (1) or front-end loader (0)</td><td>6.2.8</td></tr>
<tr><td>Swimming pool</td><td>Outdoor</td><td>6.3.2</td></tr>
<tr><td>Eyecare</td><td>Miscellaneous</td><td>6.4.3</td></tr>
<tr><td>Drinking</td><td>Indoor</td><td>$$WU = V$$
Where:
WU = water use (L/c/d)
V = volume of drinking water (L)</td><td>6.2.1</td></tr>
<tr><td>Toilets</td><td>Indoor</td><td>$$\mathrm{WU} = \mathrm{Occur}_{\mathrm{T-type}}\colon\{\mathrm{F}\,[\mathrm{ratio}_{\mathrm{full}}\,\mathrm{V}_{\mathrm{full}} + (1 - \mathrm{ratio}_{\mathrm{full}})\,\mathrm{V}_{\mathrm{half}}]$$
Where:
WU = water use (L/c/d)
F = frequency of toilet flushing (flushes/c/d)
V_{full} = volume of a full flush (L)
V_{half} = volume of a half flush (L)
$ratio_{full}$ = ratio of full flushes to half flushes
Occur $_{T\text{-}type}$ is a discrete variable between 1 and 4 which prescribes toilet type, where 1 = 9.0 L Single; 2 = 4.5/9.0 L Dual; 3 = 6.0 L Single; 4 = 3.0/6.0 L Dual and 5 = 2.5/4.0 L Dual. The toilet type will dictate the full and half flush volumes.</td><td>6.2.2</td></tr>
</table>

Shower	Indoor	$$WU = \mathrm{Occur}_s\, F\, D\, [\mathrm{Occur}_{\,s-low}\, \mathrm{I}_{low} + (1 - \mathrm{Occur}_{\,s-low})\, \mathrm{I}_{normal}]$$ Where: WU = water use (L/c/d) F = frequency (events/c/d) D = duration (s) I_{normal} = flowrate of a normal shower head (L/s) I_{low} = flowrate of a low flow shower head (L/s) $Occur_s$ is a binomial variable (0,1) prescribing the use of shower (1) $Occur_{s\text{-}low}$ is a binomial variable (0,1) prescribing the presence (1) or absence (0) of a low flow shower head	6.2.3
Bath	Indoor	$$WU = [Occur\ F\ V]_{cleaning} + [Occur\ F\ V]_{relax}$$ Where: WU = water use (L/c/d) F = frequency (events/c/d) V = volume (L) $Occur_{cleaning}$ is a binomial variable (0, 1) prescribing the occurrence of bathing for cleaning $Occur_{relax}$ is a binomial variable (0, 1) prescribing the occurrence of bathing for relaxation purposes In the case of the bath, $Occur_{cleaning}$ and $Occur_{relax}$ are mutually exclusive, meaning if one occurs, the other cannot occur. The use of the bath in this study is dictated by the use of a shower for cleaning purposes.	6.2.4

Hand washing	Indoor	$WU = \mathrm{F\ I\ D}$ Where: WU = water use (L/c/d) I = flow rate of the tap (L/s) D = duration (s) $\mathrm{F} = \mathrm{F_T} + \mathrm{F_{food\ prep}} + \mathrm{F_{eating}} + \mathrm{Occur_P}\ \mathrm{F_{handling\ pets}} + \mathrm{F_{MS}}$ Where: F_T = frequency of toilet use (events/c/d) $F_{food\ prep}$ = frequency of food preparation (events/c/d) F_{eating} = frequency of eating food (events/c/d) $F_{handling\ pets}$ = frequency of handing pets (events/c/d) F_{MS} = frequency of miscellaneous hand washing events (events/c/d) $Occur_p$ is a binomial variable (0, 1) prescribing the presence of a pet in the house	6.2.5
Shaving	Indoor	$\mathrm{WU} = \mathrm{Occur_M}\ [\mathrm{Occur_{SH/M}}\ (\mathrm{F_{SH/M}}\ \mathrm{V_{SH}})] + (1 - \mathrm{Occur_M})\ [\mathrm{Occur_{SH/F}}\ (\mathrm{F_{SH/F}}\ \mathrm{V_{SH}})]$ Where: WU = water use (L/c/d) V_{SH} = volume of water required for shaving (L) $F_{SH/M}$ = frequency of shaving for males (events/c/d) $F_{SH/F}$ = frequency of shaving for females (events/c/d) $Occur_M$ = is a binomial variable (0, 1) prescribing whether the occupant of the house is male (1) or female (0) $Occur_{SH/M}$ = is a binomial variable (0, 1) prescribing whether the male occupant shaves $Occur_{SH/F}$ = is a binomial variable (0, 1) prescribing whether the female shaves	6.2.7

Cooking	Indoor	$$WU = V$$ Where: WU = water use (L/c/d) V = volume of water used for cooking (L)	6.2.9
Dishwashing – automatic	Indoor	$$WU = \mathrm{Occur}_{\mathrm{DW}}\left[(\mathrm{F\ V})_{\mathrm{DW}} + (\mathrm{Occur\ F\ V})_{\mathrm{pre-wash}}\right]$$ Where: WU = water use (L/c/d) F = frequency (events/c/d) V = volume (L) $\mathrm{Occur}_{\mathrm{DW}}$ is a binomial variable (0, 1) prescribing the use of an automatic dishwasher $\mathrm{Occur}_{\mathrm{pre\text{-}wash}}$ is a binomial variable (0, 1) prescribing the occurrence of pre-washing dishes prior to putting them in the dishwasher	6.2.10
Dishwashing – by hand	Indoor	$$WU = (1 - \mathrm{Occur}_{\mathrm{DW}})[\mathrm{F}_{\mathrm{non-DWowner}}\ \mathrm{V}_{\mathrm{HWD}}] + \mathrm{Occur}_{\mathrm{DW}}[\mathrm{F}_{\mathrm{DWowner}}\ \mathrm{V}_{\mathrm{HWD}}]$$ Where: WU = water use (L/c/d) $\mathrm{F}_{\mathrm{non\text{-}DWowner}}$ frequency of washing dishes by hand for a non-dishwasher owner (events/c/d) $\mathrm{F}_{\mathrm{DWowner}}$ frequency of washing dishes by hand for a dishwasher owner (events/c/d) $\mathrm{V}_{\mathrm{HWD}}$ = volume of water used for washing dishes by hand (L) $\mathrm{Occur}_{\mathrm{DW}}$ is a binomial variable (0, 1) prescribing the presence of using an automatic dishwasher (1)	6.2.11

Irrigation	Outdoor	$$WU = \text{Occur}_{IR}:\{\text{F I D}$$ Where: WU = water use (L/c/d) F = frequency of irrigation system used (events/c/d) I = flow rate of irrigation system used (L/s) D = duration of irrigation system used (s) Occur$_{IR}$ is a discrete variable between 1 and 4 which describes irrigation type, where 1 = hand-held hose; 2 = manual sprinkler; 3 = automatic sprinkler; 4 = other/unknown. The irrigation type will dictate the frequency, duration and flow rate of the irrigation event	6.3.1
Pets	Miscellaneous	$$WU_p = \text{Occur}_p\left[\text{No.}\left(\text{V}_{\text{consumption}} + \text{V}_{\text{cleaning}} + \text{V}_{\text{bathing}}\right)\right]_p$$ Where: WU$_p$ = water use for the pet (L/c/d) No. = number of the type of pet V$_{consumption}$ = volume of water used for consumption by the pet (L) V$_{cleaning}$ = volume of water used for cleaning of pet facilities (L) V$_{bathing}$ = volume of water used for bathing pet (L) p = type of pet Occur$_p$ is a binomial (0,1) variable prescribing whether the pet type is present (1)	6.4.1

Car wash	Outdoor	$$\mathrm{WU} = \mathrm{Occur}_{\mathrm{CW-type}}\colon \begin{cases} \text{if } 1\colon (\mathrm{F\ V})_{\mathrm{hm}} \\ \text{if } 2\colon \mathrm{Occur}_{\mathrm{hm}}\ (\mathrm{F\ V})_{\mathrm{hm}} + (1 - \mathrm{Occur}_{\mathrm{hm}})\ (\mathrm{F\ V})_{prof} \\ \text{if } 3\colon (\mathrm{F\ V})_{\mathrm{prof}} \end{cases}$$ Where: WU = water use (L/c/d) F_{hm} = frequency of car washing at home (events/c/d) F_{prof} = frequency of car washing at a professional car wash(events/c/d) $Occur_{hm}$ is a binary variable (0,1) which prescribes whether a 50/50 car wash is at home (1) or at a professional car wash (0) $Occur_{CW\text{-}type}$ is a discrete variable between 1 and 3 which describes car wash type, where 1 = home car wash, 2 = 50/50 home and professional car wash and 3 = professional car wash	6.3.3

6.2.2 Toilets

Toilet use is not restricted to only household use as toilets are frequented outside of the home in public places such as work and shopping centres. Consequently, data for weekday household toilet use could not be used to model the frequency of toilet flushes. Therefore, data for weekend toilet use was used, as it is assumed that on average residents spend the majority of their weekend at home. The frequency of toilet use was, therefore, determined by looking at weekend toilet use frequency. Normal toilet use for the ultimate consumption lifestyle level was modelled as follows:

- The minimum flush frequency was 2.0 times per day which corresponds to a defecation frequency of one to two times a day (Heaton et al., 1992);
- An average flush frequency of 5.0 flushes/c/d was used in accordance with Roberts (2005), Rosenberg (2007), Mayer et al. (1999), DeOreo (2011) and Hussien et al. (2016);
- Gleick et al., (2003) found that the volume of water used per toilet flush has become more predictable over time. Consequently, deterministic rather than stochastic values for flush volumes were used;
- The flush volume was dictated by the toilet type. For example, a 4.5/9.0 L dual flush toilet would have a half flush volume of 4.5 L/flush and a full flush volume of 9 L/flush;
- The percentage distribution of toilet flushes requiring a full flush was taken from Roberts (2005) and was found to be a uniform distribution between 40% and 60%; and
- Blokker (2006) provided penetration rates for toilets in the Netherlands, a modern developed country. It was considered appropriate to use the penetration rates of Blokker (2006) in this study as it is primarily aimed at modelling for developed urban households. Gleick et al. (2003) estimated a toilet replacement rate of 4% per year. It was assumed that all replaced (i.e. retrofitted) toilets are replaced equally by either a 3/6 L dual-flush or a new to the market 2.5/4.0 L dual-flush toilet, based on the percentage of toilets sold internationally (see Table 5.1). Therefore, the distribution of toilet types was adjusted for the current day toilet distribution by replacing the 9.0 L, 4.5/9.0 L dual and 6.0 L toilets, equally, with 3.0/6.0 L and 2.5/4.0 L dual flush toilets, at a rate of 4% per year. The results are consistent with the toilet type distribution found in an end-use study in Yarra Valley, Australia (Roberts, 2005). Equation 6.1 was used to calculate the replacement value of each toilet. The distribution of the penetration rate, of each toilet type, before and after adjustment for time is shown in Table 6.2. The penetration rate values used as probability inputs for the discrete distribution used to determine $Occur_{T\text{-}type}$. There are lower flush volume dual-flush toilets available in the market, however, they are not common and would, thus, not be found in that many

households. Therefore, dual flush toilets with flush volumes less than 2.5/4.0 L were not considered in this study.

$$PR_{new} = PR_{old}[1 - 0.04\,(year_2 - year_1)] \qquad \textit{Equation 6.1}$$

Where: PR = penetration rate

$year_1$ = 2006

$year_2$ = 2019

Table 6.2: Toilet penetration rate before and after adjustment for time

Toilet Type	**Penetration rate before adjustment (%)** (Blokker, 2006)	**Penetration rate after adjustment (%)**
9.0 L single	33.3	16.0
4.5/9.0 L dual	22.2	10.7
6.0 L single	11.1	5.3
3.0/6.0 L dual	33.3	50.6
2.5/4.0 L dual	0.0	17.3

6.2.3 Shower

The first parameter to be determined with regards to the shower water use activity was whether a shower was being used for cleaning purposes. A percentage use of showers for cleaning purposes was chosen as 86%, an average of the values determined by Browne et al. (2014) and Matos et al. (2013), was used for the study. That is, a binomial distribution with an 86% chance of a shower being used for cleaning purposes was used to determine if a shower was being used for cleaning purposes. Due to the inter-dependent nature of the shower and bath water use activities, if a shower was not being used for cleaning purposes then a bath was assumed to be used for cleaning purposes. The presence of a low flow shower head was then determined, with a binomial distribution, using a low flow showerhead penetration rate of 55% (Grafton et al., 2011). A uniform distribution was used to model the flow rate for both normal and low flow showerheads. A minimum flow rate of 0.1 L/s was chosen for both normal and low flow showerheads and a maximum flow rate of 0.33 L/s and 0.15 L/s was chosen for normal and low flow showerheads, respectively. A lognormal distribution was used for both the duration and frequency of showering. A mean of 426 s and a standard deviation of 228 s was used for shower duration and a mean of 0.85 showers/c/d and a standard deviation of 0.49 showers/c/d was used for shower frequency.

6.2.4 Bath

Baths can be used to clean oneself or they can be used for relaxation purposes, in addition to showering for cleaning purposes, therefore, the purpose of the bath activity was required to calculate water use. Since probability of bathing for cleaning purposes is dependent on whether a shower was used for cleaning purposes, the probability of bathing for cleaning purposes was determined by subtracting the probability of showering from 100%, resulting in a 14% probability. The frequency of bath events for cleaning purposes was taken to be the same as that of the shower events (i.e. a lognormal distribution with mean 0.85 baths/c/d and standard deviation 0.49 baths/c/d) as they serve the same purpose.

Bathing for relaxation was only considered if showering was used as the means of bodily cleaning, as a bath for cleaning would double up as a relaxation bath. The percentage occurrence of bathing for relaxation was determined by taking the overall bath occurrence percentage of 36% as determined by Blokker et al. (2010) and subtracting the percentage occurrence of baths used for cleaning (14%), resulting in a percentage occurrence of 22%. Meaning only 22% of people who shower for cleaning would also take baths for relaxation. The minimum frequency for bathing as found by Blokker et al. (2010) of 0.044 baths/c/d was used as the frequency of bathing for relaxation. The bath volume ranged from 80 to 150 L in accordance with the normal bath sizes found in literature.

6.2.5 Hand washing

Hand washing frequency was a parameter that was dependent on several other parameters, as other activities lead to the need to wash hands. The parameters that affected hand washing frequency are the frequency of toilet use, frequency of food preparation, frequency of eating, the occurrence of a pet and in turn the frequency of handling the pet, and the frequency of miscellaneous hand washing events. A Poisson distribution was used to model all hand washing frequencies. The values used for the frequencies contributing to the frequency of hand washing are summarised in Table 6.3. Even though it has been found that at the absolute minimum hands should be washed is after a defecation toilet event, it is assumed for healthy living that hands are washed after any toilet event. Due to the lack of literature on frequency of food preparation as well as miscellaneous hand washing events, an engineering estimate was required. Eating frequency in the United States is on average three to five times a day (Kant, 2018; Kerver et al., 2006), a value of three times a day was used in the LCD model. A minimum eating frequency of 1 events/c/d and maximum of 6 events/c/d were applied as boundary limits. The flow rate of a tap will vary depending on whether the tap has a flow restrictor on it and on how hard the tap has been turned on. Therefore, a tap flow rate between 0.10 and 0.33 L/s, in accordance with Blokker et al. (2010) and Rosenberg (2007), was used for this study. A lognormal distribution with mean of 10 s and standard deviation of 5 s was used for hand washing duration, such that the requirements stipulated by the Centre for Disease Control and Prevention (2016) and WHO (2009) for hygienic hand washing be met.

Table 6.3: Frequency parameters contributing to the frequency of hand washing

Parameter	Mean (λ)	Minimum	Maximum
Frequency of food preparation (events/c/d)	1.0	0.5	3.0
Frequency of eating (events/c/d)	3.0	1.0	5.0
Frequency of handling pets (events/c/d)	2.0	-	-
Frequency of miscellaneous hand washing (events/c/d)	1.5	-	-

6.2.6 Brushing teeth

The American Dental Association (2019) recommend brushing teeth twice a day. However, it is not uncommon for more or less frequent brushing to occur (Chestnutt et al., 1998). Therefore, a Poisson distribution with mean (λ) frequency of 2 brushes/d and a maximum frequency of 4 brushes/d was used in the LCD model. The beaker method prescribed by Chestnutt et al. (1998) was used as a minimum water requirement for brushing teeth. It was assumed that one glass contains 0.25 L of water. Even though a glass of water is deemed adequate for cleaning of the mouth, cleaning of a used toothbrush often requires running water which will result in higher water use Matos et al. (2013). Therefore, a triangular distribution with a minimum, maximum and most common values of 0.25 L/event, 0.5 L/event and 1.5 L/event, respectively, were used in the LCD model.

6.2.7 Shaving

The occurrence of shaving varies significantly amongst different cultures and even religious groups in different regions of the world; with some groups shaving frequently and others shaving infrequently or never. Therefore, the percentage of men and women that shave and the frequency of shaving varies in literature depending on the demographics studied. The LCD model survey was used when populating the model for shaving. The survey was chosen as it was answered by a sample group which covered varying ages and global locations, giving the best range of data available. The frequency and occurrence of shaving is dependent on whether the occupant is male or female, therefore, the LCD model survey results were split between male and female responses. The proportion split of males to females in the world is approximately 105:100 (WHO, 2012) and was used to determine whether the simulated household would be occupied by a male or a female, such that shaving frequency could be determined. The LCD model survey results showed that 79% of men and 89% of women shave using water. The resultant distribution for each shaving frequency category specified in the survey was used in the development of the LCD model and is summarised in Table 6.4. The volume of water used for shaving varied between 0.1 and 7.0 L (Matos et al., 2013).

Table 6.4: Distribution of shaving frequency amongst males and females from LCD survey

Frequency of Shaving (events/c/d)	Percentage Distribution – Male	Percentage Distribution – Female
0.14	25.5	41.9
0.29	38.2	39.2
1.00	34.5	18.9
2.00	1.8	0.0

6.2.8 Clothes washing

Blokker et al. (2010) determined a penetration rate for clothes washing machines to be 98% in urban households in The Netherlands. Nineteen years later it can be assumed that the penetration rate would have increased to close to 100%. This study only considered urban households, therefore for the purpose of this study, a worldwide penetration rate of 100% for clothes washing machines was assumed.

Washing machines come in two different forms, a front-end loader and a top-end loader, both using different volumes of water per regular cycle. Table 5.2 was used to determine the distribution of different volumes of washing machines and the prevalence of each volume range. A penetration rate of 37% for top-end loaders was determined from Botha et al. (2018) who studied 8573 washing machine sales and determined the proportion split between top-end loader and front-end loader sales.

In accordance with the studied literature, a normal distribution, with mean of 0.31 washes/d and standard deviation of 0.11 washes/d was used for clothes washing frequency. Since a single-person household was used for this study it was considered realistic to prescribe minimum and maximum wash frequencies that were in line with the lifestyle of a single-person household. Consequently, a minimum wash frequency of 0.07 washes/c/d (a fortnightly wash) and a maximum wash frequency of 0.43 washes/c/d (a wash on 3 days of the week) was set.

6.2.9 Cooking

The volume of water used in cooking food followed a uniform distribution with a minimum volume of 0 L and a maximum volume of 1.6 L. The minimum volume was based on the assumption that households that don't cook starches may not require water for cooking every day. The maximum volume was determined from Thompson et al. (2001), Gleick (1996) and Hussien et al. (2016).

6.2.10 Dishwashing – automatic

Not all households have automatic dishwashers, therefore, the penetration rates of dishwashers in urban households determined by Blokker et al. (2010), Gleick (2003) and the European and American penetration rates determined by Vinogradova et al. (2012) were averaged and employed as inputs in the LCD model. The resultant dishwasher penetration rate was 53%. Pre-rinsing of dishes has a percentage occurrence of 33%; an average of the values determined by Richter (2011) and Vinogradova et al. (2012). The volumes for the dishwasher use was determined by averaging the percentages of each dishwasher volume range in Table 5.3 and using the resultant distribution, summarised in Table 6.5. Dishwasher frequency for the modelled single-person household ranged from 0.25 to 0.3 events/c/d. The volume of water for pre-rinsing dishes of between 3 and 7 L/pre-rinse, with a most common volume of 5 L/pre-rinse (a triangular distribution) prescribed by Richter (2011) was used for pre-rinse volume.

Table 6.5: Percentage distribution of dishwasher volumes used in the LCD model

Dishwasher Volume Range (L)	Percentage Distribution
6.5 – 9.0	16.0
9.5 – 11.0	40.9
11.5 – 13.5	39.2
14.0 – 15.0	3.9

6.2.11 Dishwashing – by hand

Hand washing dishes is done even with the presence of a dishwasher; however, the frequency of hand washing dishes differs with the presence or absence of a dishwasher. The frequency of hand washing dishes with and without the presence of a dishwasher was attained from Table 5.4. A volume of hand washing dishes of between 4 and 11 L/wash as prescribed by Berkholz et al. (2010) was used for the model.

6.2.12 Cleaning the kitchen counters

The frequency of cleaning the kitchen counters is dictated by the frequency of preparing food, therefore, the same values found in Table 6.3 for the frequency of food preparation were used. The volume of water used for cleaning the kitchen counters was based on a crude estimate due to the lack of reported data. A lognormal distribution was used with a mean of 1 L/event, a standard deviation of 0.5 L/event and a minimum and maximum of 0 L/event and 2 L/event were chosen.

6.2.13 Cleaning the house

It was assumed that house cleaning included washing of floors and bathrooms. All water for washing was assumed to come from a bucket filled with water. Larger or more soiled houses will require more buckets of water as the water will get dirty and will require refilling. Therefore, the number of buckets used for cleaning followed a lognormal distribution with a mean of 2 buckets/wash and a standard deviation of 0.5 buckets/wash as suggested by Rosenberg (2007). The volume of a bucket was adapted from that suggested by Rosenberg (2007), using some subjective judgement resulting in a lognormal distribution with a mean volume of 6 L/bucket and a standard deviation of 2 L/bucket. The frequency of cleaning the house was taken from the consumer survey, summarised in Table 6.6, as literature values were not available. The answers to the REAL lifestyle level were used for all lifestyle levels except the ABC lifestyle level, where the ABC answers were used.

Table 6.6: Percentage distribution of house washing frequency from the LCD survey

House washing frequency (washes/week)	Percentage distribution	
	ABC	REAL
0.3	37.7	12.2
1.0	40.9	46.8
2.0	16.4	27.6
7.0	5.0	13.5

6.2.14 Indoor plants

Based on reported values it was estimated that about 45% of urban households have at least one indoor plant which requires watering. The volumes of water required for indoor plants will vary depending on the number of indoor plants and the plant size; a range of between 0.25 and 2 L/c/d was used for the LCD Model.

6.3 Outdoor water use

6.3.1 Irrigation

A penetration rate of irrigated gardens of 63% was used in accordance with Pullinger et al. (2013). It was assumed that irrigation was not continuous all year round and only occurred during non-rainy seasons as suggested by Roberts (2005) and Rosenberg (2007). An irrigation season ranging between 20 and 40 weeks was chosen in accordance with literature values. Three irrigation types, namely hand-held hose, manual sprinkler and automatic sprinkler were considered individually. All other irrigation types were grouped into an “other” category. The distribution of irrigation types, the frequency (using a triangular distribution), flow rate (using a lognormal distribution) and the duration (using a lognormal distribution) was adapted from Roberts (2005) and are summarised in Table 6.7.

Table 6.7: Parameters used to determine water use for irrigation (Roberts, 2005)

Irrigation type	Percentage distribution (%)	Frequency (events/c/d)			Flow rate (L/s)		Duration (s)			
		μ	Min	Max	μ	σ	μ	σ	Min	Max
Hand-held hose	57	0.46	0.14	1.00	0.25	0.05	1500	300	300	3600
Manual sprinkler	23	0.47	0.14	1.00	0.32	0.05	4080	900	900	7200
Automatic sprinkler	6	0.56	0.14	1.00	0.26	0.05	3420	900	900	7200
Other	14	0.30	0.14	1.00	0.26	0.05	1680	300	300	3600

6.3.2 Swimming pool

Only outdoor swimming pools were considered in this study. It can be assumed that only countries with warm climates will have private home swimming pools. Therefore, it was decided to implement a temperature threshold over which a countries average temperature must fall in order to be considered to have a significant enough amount of swimming pools to be included in the model. For the LCD model, an average yearly high temperature of 23˚C was used as the temperature threshold. 78% of countries fell within the temperature threshold (Trading Economics, 2015). However, many warm countries are developing countries in Africa and South America and a luxury such as a swimming pool is not an option for most of the households in these countries. Therefore, it was assumed that only 60% of the countries that meet the temperature requirement will have a penetration rate of swimming pools that is in line with that found in literature for urban areas in developed countries. A penetration rate of a private swimming pool on a property of 24% was considered in this study (Fisher-Jeffes et al., 2014; Llausàs et al., 2018; Rathnayaka et al., 2014; Water Resources Engineering, 2002). The resultant penetration rate of swimming pools in a household was calculated by multiplying the countries with temperatures above 23˚C by the percentage of countries that would have swimming pools and the penetration rate of swimming pools, which gives a final penetration rate of 11%. Backwashing and filling of swimming pools were grouped as one activity for the purpose of this model. A triangular distribution with a most common frequency of 0.03 events/c/d, a minimum frequency of 0.01 events/c/d and a maximum frequency of 0.14 events/c/d was chosen for the backwash and fill frequency. A lognormal distribution with a mean of 300 L/event, a standard deviation of 100 L/event and a minimum and maximum of 100 L/event and 600 L/event, respectively, were used for the backwash and fill volume.

Since the volume a swimming pool consumes is based on climatic factors that affect evaporation and effective rainfall, estimating general water use for a swimming pool is a crude estimate. Should more accurate results be required by future researchers, the model would have to be modified, as the average temperature, pan evaporation and rainfall of the area will help refine the results. Modification for specific regions was not done in this study.

6.3.3 Car washing

Water is attributed to a person regardless of the location of the water use. Therefore, car washes both at home and at a professional car wash were considered for this study. The International Car Washes Association's data on the distributions of car washes between, home, professional and 50/50 was used to split the types of car washes (ICA, 2017). The frequency of home and professional car washes was determined by averaging out the values in Table 5.5. The volume of home car washes was determined from values found by Rosenberg (2007), Smith and Shilley (2009) and Janik and Kupiec (2007); while the volume of professional car washes was taken from Janik and Kupiec (2007). A summary of the percentage distribution, the frequency and the volume (minimum and maximum values for uniform distribution) of water used for each car wash type is summarised in Table 6.8.

Table 6.8: Summary of parameters contributing to car wash water use

Car wash type	Percentage distribution	Percentage break down of frequency of car wash events						Volume (L)	
		Frequency (events/c/d)						Min	Max
		0.00	0.01	0.02	0.03	0.08	0.14		
Home	13.5	3.0	13.0	14.0	32.0	27.0	11.0	46.0	440.0
Professional	58.5	4.5	14.5	32.5	28.0	17.0	4.5	61.0	270.0
50/50	28.0								

6.4 Miscellaneous Water Use

6.4.1 Pets

Most domestic pets require water or lead to increased household water use. In an attempt to model the water use of pets, values were required to model pet penetration (whether a pet would be present in a household or not), number of each type of pet and the volume of water required for the different types of pets. The average penetration rates for each pet type from the literature values in Table 5.6 (results summarised in Table 6.9) were used in the model to determine the presence or absence of a specific pet in a household. Once the presence or absence of each type of pet was known, the number of each of the type of pet present was determined using a discrete distribution from the results of the LCD Model survey, summarised in

Table 6.10.

The volume of water required for each pet was determined according to the requirements for consumption, bathing and cleaning of the animal's cage, bowl or other accessories, where applicable. The volumes were calculated, for each pet, in accordance with the recommendations stipulated in literature as summarised in Chapter 5.4.1. A summary of the volumes used for consumption, cleaning and bathing given in the format (minimum; maximum) as required for the uniform distribution used to model the volume is given in Table 6.11. Outdoor fish ponds are excluded from Table 6.11 as the volume parameters used to calculate the volume for outdoor fish ponds does not conform to the constraints of consumption, cleaning and bathing volumes. The volume requirements for outdoor fish ponds include a minimum and maximum volume of 8.5 L/pond/d and 100.0 L/pond/d, respectively, for (bi)weekly maintenance depending on the size of the fish pond; as well as a minimum and maximum volume of 4.7 L/pond/d and 54.8 L/pond/d, respectively, for seasonal maintenance.

Table 6.9: Penetration rate of pet type into a home (see Table 5.6)

Pet type	Penetration rate (%)
Dogs	33
Cats	24
Birds in an aviary	2
Birds in a cage	4
Small Animals	2
Indoor fish	7
Outdoor fish	5
Reptile	2

Table 6.10: Percentage distribution of the number of pet type owned from LCD survey

Number of pets owned	Dogs	Cats	Bird aviary	Bird cage	Small Animals	Indoor fish	Outdoor fish	Reptile
1	32.2	53.8	66.7	75.0	85.7	75.0	83.3	100.0
2	55.9	38.5	16.7	12.5	14.3	25.0	0.0	0.0
3	8.5	7.7	0.0	0.0	0.0	0.0	0.0	0.0
4	3.4	0.0	16.7	0.0	0.0	0.0	0.0	0.0
>5	0.0	0.0	0.0	12.5	0.0	0.0	16.7	0.0
	100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 6.11: Volume ranges (L/d) used to calculate water use for pets (min; max)

Volume for	Dogs	Cats	Bird aviary	Bird cage	Small Animals	Indoor fish	Reptile
Consumption	(0.5;7.4)	(0.4;0.5)	(1.0;12.0)	(0.3;1.8)	(0.1;0.3)	-	(0.1;0.5)
Cleaning	-	(0.1;0.3)	(0.7;1.6)	(0.3;2.1)	(0.3;1.6)	(0.1;3.0)	(0.1;0.3)
Bathing	(0.1;1.6)	-	-	(0.2;0.9)	-	-	-

6.4.2 Leakages and real losses

Even though leaks can amount to a large proportion of a household's water use, only a small number of houses have significant leaks. The Water Corporation's penetration rate of leaks of 17% was used in the LCD model. A uniform distribution with a range of leakage volumes from 15 L/c/d to 82 L/c/d was used in accordance with Liu et al. (2016), Mayer et al. (1999) and Water Corporation (2010).

6.4.3 Other water uses

The miscellaneous water use activities considered in this study include the following:

- Eyecare
- Fridge cleaning
- Empty dishwasher run
- Empty washing machine run
- Washing of house windows
- Other water uses or emergencies such as fires and illnesses

Water use associated with eyecare has limited information available in literature meaning engineering estimates were required when determining distributions for eyecare parameters.

Eyecare water use includes water for washing hands before and/or after handling the product and water used for cleaning glasses or contact lens cases (Heiting, 2019; Radford et al., 2009). Since hand washing is recommended, at least, every time before handling eye products, a frequency of at least once a day for glasses wearers and twice a day for contact lens wearers would be expected. For this reason, a Poisson distribution with a mean of 2.25 events/d and a maximum of 3 events/d was used for frequency of eye care. The volume of water required per event was chosen to have a lognormal distribution with mean 0.75 L/event and a standard deviation of 0.25 L/event. The percentage occurrence of 61% for glasses and contact lens wearers, suggested by CBS (2013) was used as a wholistic value for all eye care.

The volume of water required for cleaning windows is dependent on the number of windows in the house. It was assumed that most windows are cleaned with a bucket of water. The volume of a bucket was taken to be the same as that used for cleaning the house and the number of buckets used for washing followed a Poisson distribution with a mean of 0.5 buckets/event and a minimum of 1 buckets/event. The frequency of window washing was modelled according to Rosengren (2014). A triangular distribution with a minimum of 3 washes/year, a mean of 4 washes/year and maximum of 12 washes/year was used for the model development.

Emergency and other water use encompasses any water use that is random in occurrence, such as water for a small fire or excess water used when sick or water used for cleaning of sports equipment. Engineering judgement was required to make a crude estimate of the frequency and volume of water for emergency and other water uses. An emergency event can occur only one time in a year, however, random tasks requiring water can happen as frequently as once a week. Since there is an even chance of a random water use occurring any frequency between once a month and once a year, a uniform distribution with a minimum frequency of 1 events/year and a maximum frequency of 52 events/year was used in the development of the model. The volume of water required for these random water use events is also extremely variable. A uniform distribution with a minimum volume of 1 L/event and a maximum volume of 50 L/event was chosen for other water uses.

Fridge, dishwasher and washing machine cleaning practices as prescribed by Leverette (2019) were used when developing the LCD model. A lognormal distribution was used to model the frequency requirements of the fridge, dishwasher and washing machine cleaning, as well as the volume requirements of the fridge cleaning; a summary of the mean and standard deviations for each frequency and volume parameter is provided in Table 6.12. The volume of the washing machine and dishwasher empty run will be equal to the volume of a normal run as discussed in section 6.2.8 and section 6.2.10, respectively.

Table 6.12: Summary of requirements for miscellaneous cleaning activities

Parameter	Mean	Standard deviation
Volume of fridge cleaning (L/event)	1.000	0.500
Frequency of fridge cleaning (events/c/d)	0.010	0.005
Frequency of empty dishwasher run (events/c/d)	0.030	0.005
Frequency of empty washing machine run (events/c/d)	0.030	0.005

6.5 Adjustment for different lifestyle levels

6.5.1 Ultimate consumption

Section 6.2 to Section 6.4 describe the development of the ultimate consumption lifestyle level in the LCD model. A summary of each model input parameter and the probability distribution and constraints used to describe the parameters used in the development of the ultimate consumption lifestyle level is given in Table C1 in Appendix C. The subsequent sections discuss the modifications made to the ultimate consumption lifestyle level for each lifestyle level.

6.5.2 Esteemed needs

Esteemed needs consumption aimed to model a single-family household under low level water restrictions or a household that lives a lifestyle in which water use is conservative; meaning indoor use was unrestricted and restricted outdoor use was allowed. The esteemed needs lifestyle level aimed to fulfil the esteemed needs of Maslow's (1948) hierarchy of needs. The outdoor restrictions are in accordance with the bylaws for level 3 water restrictions implemented by The City of Cape Town (The City of Cape Town, 2019) and stage 4 water restriction bylaws set out the by Western Australia Water Agency (Western Australia Water Agency, 2017). The following parameters (summarised in Appendix C, Table C 2) were adjusted from those used to model the ultimate consumption:

- Irrigation was restricted to handheld hose or bucket or watering can any time and any other irrigation was allowed twice a week. Therefore, the frequency of manual sprinklers, automatic sprinklers and other irrigation methods was adjusted to have a uniform distribution with a minimum frequency of 0.07 events/d and a maximum frequency of 0.29 events/d. All irrigation was limited to a maximum of 1 hour per event of irrigation per household. The distribution of irrigation types, the frequency (using a triangular distribution for handheld hoses and uniform distribution for all other irrigation methods), flow rate (using a lognormal distribution) and the duration (using a lognormal distribution) are summarised in Table 6.13;

- Car washes were restricted to washing with a bucket only; and
- Water use for pools was reduced by 50% due to the presence of a non-permeable solid pool cover being mandatory when the pool is not in use.

Table 6.13: Irrigation parameters used to model esteemed needs lifestyle

Irrigation type	Frequency (events/c/d)			Flow rate (L/s)		Duration (s)			
	μ	Min	Max	μ	σ	μ	σ	Min	Max
Hand-held hose	0.46	0.14	1.00	0.25	0.05	900	300	300	3600
Manual sprinkler		0.07	0.29	0.32	0.05	2700	900	600	3600
Automatic sprinkler		0.07	0.29	0.26	0.05	2700	900	600	3600
Other		0.07	0.29	0.26	0.05	1680	300	300	3600

6.5.3 Realistic everyday acceptable limited consumption

The REAL lifestyle level modelled indoor water use with no restrictions, meaning consumers were allowed to use water indoors without lifestyle changes. The REAL consumption may be used to model water use of households without outdoor spaces such as apartments, blocks of flats or households with gardens who are restricted to only indoor water use during water restriction periods. The REAL lifestyle level aimed to fulfil the belongingness and love needs of Maslow's (1948) hierarchy of needs. The following parameters (summarised in Appendix C, Table C 3) were considered when modelling REAL consumption:

- Car washes were restricted to waterless carwashes which were considered to use a negligible volume of water. The use of public transport rather than owning a car was considered to be the equivalent to using no water for car washes;
- No outdoor use was considered, unless necessary for an outdoor pet; and
- Onsite plumbing leaks or water losses were expected to be considered separately.

6.5.4 Absolute basic consumption

The ABC lifestyle level modelled water use under severe water restrictions. The REAL lifestyle level aimed to fulfil the safety needs of Maslow's (1948) hierarchy of needs. Unless stated otherwise, the restrictions placed on the water use activities were in line with suggestions and by-laws put in place by the City of Cape Town during their campaign to reduce water use during the 2017 and 2018 water restrictions (The City of Cape Town, 2018). The following parameters (summarised in Appendix C, Table C 4) were adjusted from those used to model the REAL consumption:

- Toilet flushes were limited to 3 flushes a day, with a mean flush frequency of 2 flushes/c/d;
- All 9.0 L toilets were replaced equally by either a 3.0/6.0 L or a 2.5/4.0 L dual flush toilets;
- All showerheads were replaced with low flow showerheads with a maximum flow rate of 9 L/s. The minimum flow rate was modelled at 6 L/s, as per the suggested flow rates for low flow tap fixtures;
- Shower durations are limited to a maximum of five minutes. The 10th percentile shower duration value from Botha et al. (2017) was chosen as a maximum duration as it would be expected that shower durations are restricted to the shortest studied duration. A mean of three minutes was imposed in accordance with the City of Cape Towns' recommendations;
- Shower and bath frequency were modelled according to the survey responses for shower frequency during ABC conditions. A summary of the shower frequency and percentage distribution is given in Table 6.14.
- Flow restrictors, restricting the flow to a maximum flow rate of 9 L/min were placed on all indoor taps;
- Baths volume was restricted to a maximum of 40 L/event, the minimum normal bath volume found by Jacobs (2004);
- No separate baths for relaxation, i.e. if a shower was used for cleaning purposes then a relaxation bath was not modelled;
- Hand washing frequency was reduced by 30%, as waterless hand sanitiser can be used in situations where hands are unsoiled;
- Miscellaneous hand washing events were limited to a maximum of one event per day;
- Brushing teeth was limited to the beaker technique described by Chestnutt et al. (1998);
- No shaving with water. An alternative waterless hair removal technique would be required;
- Only eye care and other emergency miscellaneous water use activities were included. I.e. no fridge, dishwasher, washing machine or window cleaning;

- Water use for other emergency miscellaneous activities was restricted to 10 L/event due to mindfulness of excessive water use during times of extreme restrictions;
- No outdoor water use whatsoever was included; and
- All water losses were excluded and would have to be modelled separately. Water losses were excluded as leak detection and repair is often employed during times of severe water restrictions.

Table 6.14: Shower frequency distribution for ABC lifestyle from LCD model survey

Shower frequency (events/c/d)	Percentage distribution
0.00	0
0.14	8.2
0.29	13.3
0.57	34.2
1.00	42.4
2.00	1.9

7 LCD Model Results for Single-Person Household

7.1 Distribution of water use

Three levels of water use were defined, namely low water use, normal water use and high water use. Normal water use fell in the range of one standard deviation either side of the mean, meaning $\mu \pm \sigma$. Water use that was lower than one standard deviation below the mean, meaning less than $\mu - \sigma$, was considered to be low water use. Water use that fell one standard deviation above the mean, meaning water use greater than $\mu + \sigma$, was considered to be high water use. The same approach was followed by Koutiva and Makropoulos (2016).

7.2 Summary of results

A summary of the mean, standard deviation, range and the normal, high and low water use is given in Table 7.1. The results showed that the variation of the water use around the mean value increased as the lifestyle level increased. The increase in lifestyle level includes non-essential water uses, such as outdoor water use, which have higher variability. Irrigation is the largest contributor to outdoor water use and has a high degree of variability in the type, frequency, flow rate and duration of the event. Consequently, overall there is higher variability in the water use for lifestyle levels that include outdoor water use activities, i.e. the esteemed needs and ultimate consumption lifestyle levels. The ABC has the smallest variation in the water use as a large amount of the variability is eliminated by placing restrictions on the water use activities.

Table 7.1: Summary statistics for Monte Carlo simulation for each lifestyle level

Lifestyle Level	ABC	REAL	Esteemed Needs	Ultimate
Mean (L/c/d)	92	175	227	314
Std Dev (L/c/d)	40	75	94	179
Range (L/c/d)	690	1434	1720	1937
Normal use (L/c/d)	52 - 132	100 - 251	133 - 321	135 - 493
High Use – >μ+σ (L/c/d)	>132	>251	>321	>493
Low Use – <μ-σ (L/c/d)	<52	<100	<133	<135

7.3 Ultimate consumption

The distribution of the expected water use for the ultimate consumption lifestyle level is given in Figure 7.1. The model results showed that ultimate per capita water consumption varied between 122 L/c/d and 680 L/c/d for 90% of the model runs, with a mean value of 314 L/c/d. The percentile values for 25% and 75% were 191 L/c/d and 380 L/c/d respectively. Based on a sensitivity analysis performed on the model, the top five factors that had the greatest effect on the variability of water use, in order of greatest effect, are whether gardens are irrigated, type of irrigation used, shower frequency, shower duration and irrigation season. Three of the top five factors affecting the variability of water use are related to irrigation. Since garden irrigation was the largest water consumer in a household and is highly variable in its water use, the absence or presence of garden irrigation will contribute to the high range of water use found in the results of the ultimate consumption lifestyle.

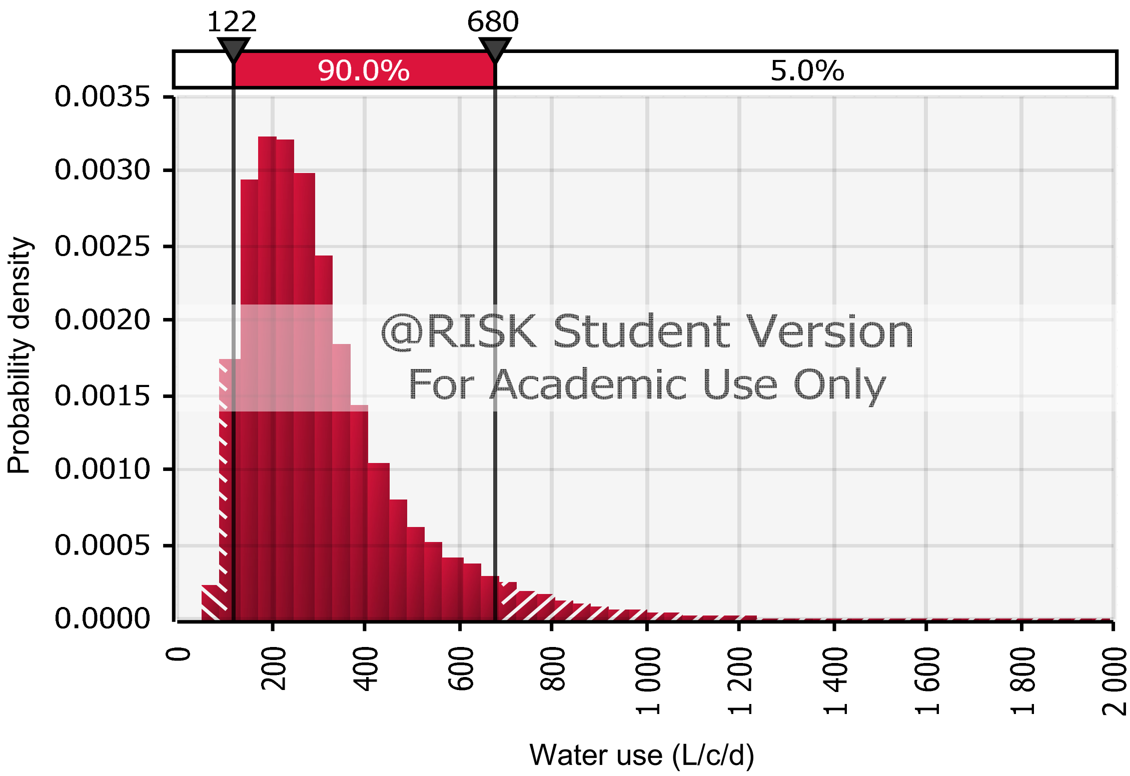

Figure 7.1: Distribution of expected per capita water use for ultimate consumption

7.4 Esteemed needs

The distribution of the expected water use for the esteemed needs lifestyle level is given in Figure 7.2. The model results showed that esteemed needs per capita water consumption varied between 113 L/c/d and 387 L/c/d for 90% of the model runs, with a mean value of 227 L/c/d. The percentile values for 25% and 75% were 164 L/c/d and 270 L/c/d respectively. The top five factors that had the greatest effect on the variability of water use, in order of greatest effect, are shower frequency, shower duration, whether gardens are irrigated, whether an outdoor pond (for outdoor fish et cetera) is present and frequency of toilet flushes.

The effect of placing early stage water restrictions (Western Australia's stage 4 and City of Cape Town's stage 3) can be seen in evaluating the difference in the results of the ultimate consumption and the esteemed needs consumption. The only factors that changed from the ultimate consumption to the esteemed needs lifestyle level were the irrigation type and time restrictions, the 50% reduction in swimming pool water use needs and the restriction of car washes to a bucket only. However, the mean water use reduced by 87 L/c/d. The reduction in mean water use between the ultimate consumption and the esteemed needs consumption shows that a conscious reduction in outdoor water use can reduce water use by up to 28%. Thus, even minor restrictions placed on outdoor water use can help in reducing overall water use. Due to the restrictions on outdoor water use, the esteemed needs lifestyle level has less variability in the results in comparison to the ultimate consumption lifestyle level.

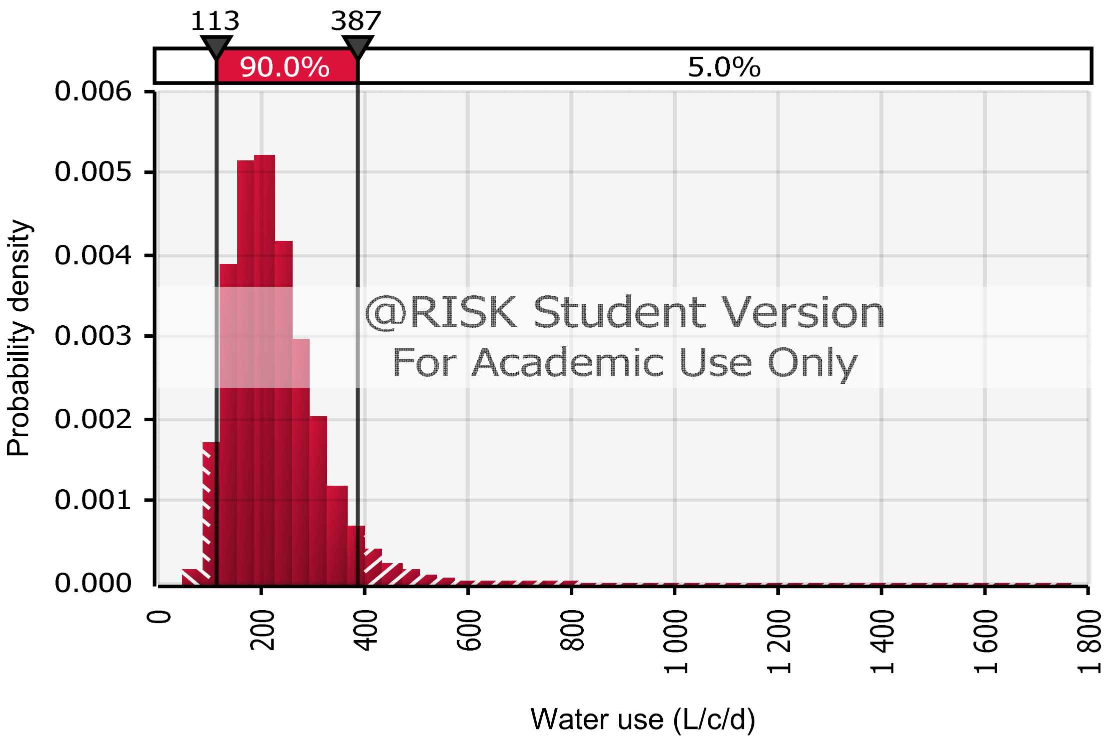

Figure 7.2: Distribution of expected per capita water use for esteemed needs lifestyle

7.5 Realistic everyday acceptable limited consumption

The distribution of the expected water use for the REAL consumption lifestyle level is given in Figure 7.3. The model results showed that REAL per capita water consumption varied between 95 L/c/d and 305 L/c/d for 90% of the model runs, with a mean value of 175 L/c/d. The percentile values for 25% and 75% were 127 L/c/d and 203 L/c/d respectively. The sensitivity analysis showed the top five factors that had the greatest effect on the variability of water use, in order of greatest effect, are shower frequency, shower duration, hand washing duration, frequency of toilet flushes and whether a household has an outdoor pond.

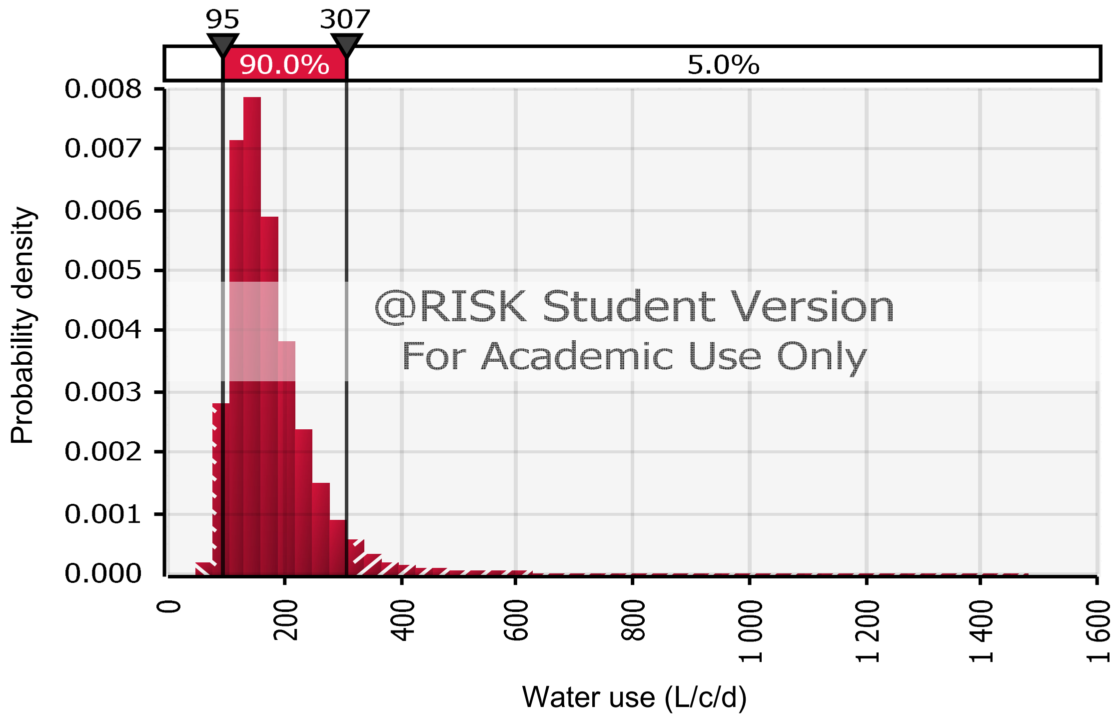

Figure 7.3: Distribution of expected per capita water use for REAL Consumption

7.6 Absolute basic consumption

The distribution of the expected water use for the ABC lifestyle level is given in Figure 7.4. The model results showed that the absolute basic per capita water consumption varied between 55 L/c/d and 151 L/c/d for 90% of the model runs. The percentile values for 25% and 75% were 71 L/c/d and 101 L/c/d respectively. The top five factors that had the greatest effect on the variability of water use, in order of greatest effect, are frequency of washing the house, whether a household has an outdoor pond, shower frequency, frequency of clothes washing and hand washing duration. The ABC is the lowest expected water use possible, while providing for all health needs, in a fully serviced urban household. The results show that a mean water use of 92 L/c/d is needed to maintain a healthy lifestyle while under severe restrictions.

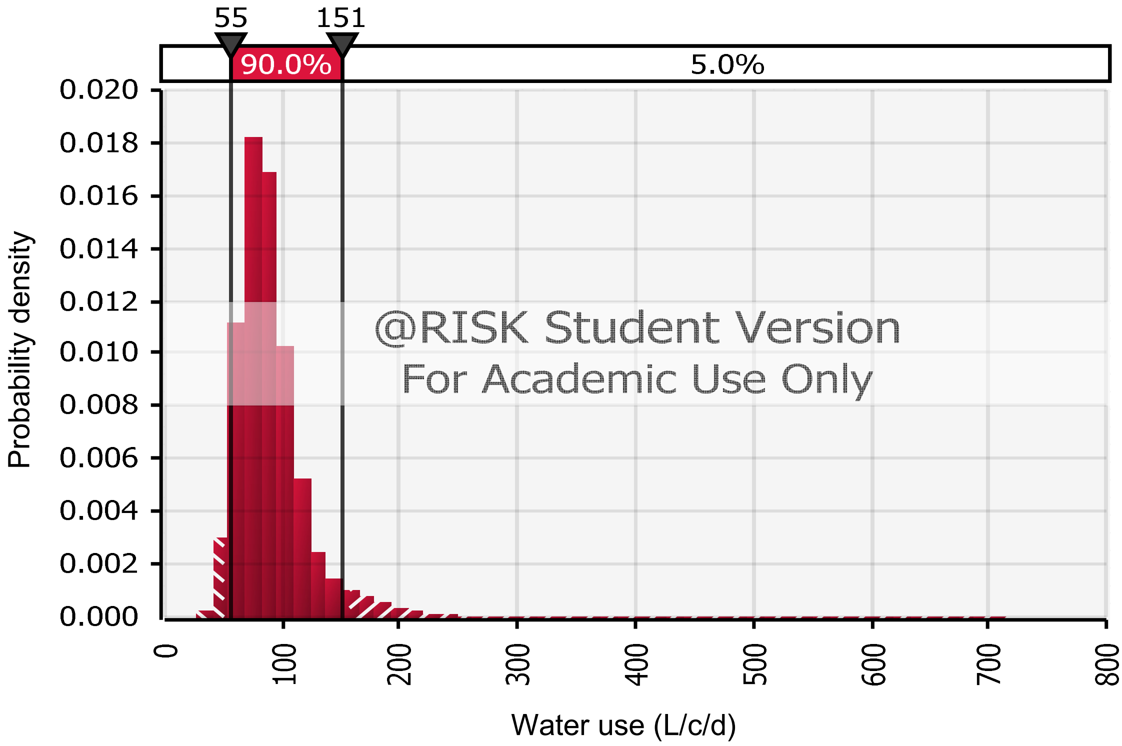

Figure 7.4: Distribution of expected per capita water use for ABC

8 Discussion

8.1 Verification of model results

8.1.1 Examining the model output for reasonableness

A thorough check was conducted for logical relationships and limiting values. The model was analysed both deterministically with set values and stochastically with the modelled input parameters. The following scenarios were considered:

- Zero values were input for each parameter ensuring that the resultant water use was zero;
- Zero values were input for outdoor water use in the esteemed needs and ultimate consumption lifestyle levels and the results compared to the REAL consumption model to verify the indoor portion of the model for each lifestyle level;
- The minimum and maximum input values were deterministically set, and the results compared to the stochastic outputs;
- Input values were adjusted up and down to ensure the model reacted accordingly; and
- Each individual water use activity was considered separately (i.e. the inputs to the parameters of all other water use activities were set to zero) and compared between each lifestyle level to ensure no errors.

8.1.2 Model results compared to published studies

All mean per capita water use values found in literature, as summarised in Appendix A, were compiled for comparison to the LCD model results. The literature water use values were filtered to remove any studies that included intermittent supply or studies on households that did not fall within the scope of this study. The results of mean water use values determined by the LCD model superimposed on a graph of the filtered literature mean water use values can be seen in Figure 8.1. The results from the model all fall well within the water use values found in literature. The ranked scatter plot included 103 different study sites summarised in Appendix A. No studies reported water use below the mean of the ABC consumption, confirming that the ABC is the minimum consumption in an urban household that has been recorded in literature. The mean consumption for the esteemed needs lifestyle level was representative of the median data. Three studies found values higher than the high use of the ultimate consumption lifestyle level. The LCD model excluded inefficient or wasteful water use, possibly explaining areas or specific results from other studies where water use is higher than the modelled values.

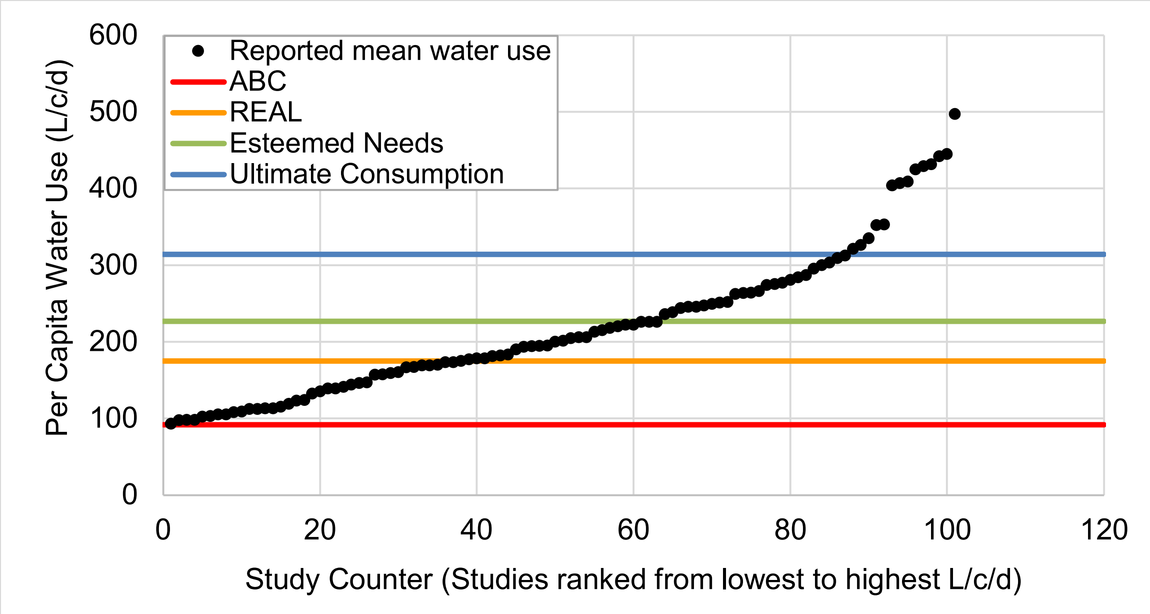

Figure 8.1: Mean literature values compared to model results for mean use per category

8.1.3 Model results compared to informal online water use calculators

There are various internet-based water use calculators that are available from water utility providers or private water-related companies. These water use calculators generally ask for information on daily water use activities, such as the number of showers, toilet flushes, laundry and dishwasher load and outdoor water use. Thereafter, a crudely estimated water use value is generated, providing the consumer with an idea of what their water use should approximately be. The water use calculators provided by the City of Cape Town (2019) and the Southwest Florida Water Management District (SFWMD) (2018) were used to determined water use values such that they could be compared to the results of the LCD model. The City of Cape Town developed a water use calculator during a period in which outdoor water use was not allowed, therefore, there is no allowance for outdoor water use in the calculator. Consequently, only the ABC and the REAL consumption lifestyle levels could be compared to the estimated values given by The City of Cape Town (2019). The water use calculator developed by the SFWMD (2018) provided for outdoor use, allowing for all lifestyle levels considered in the LCD model to be compared to the results of the water use calculator. The water use inputs and results for each lifestyle level evaluated using the water use calculators developed by the City of Cape Town and the SFWMD are given in Table 8.1 and Table 8.2, respectively. The estimated values as determined by the City of Cape Town's water use calculator are 70.4 L/c/d and 146.8 L/c/d for ABC and REAL consumption, respectively. The result of the ABC consumption is 23% lower than that of the LCD model; while the result of the REAL consumption is 16% less than the LCD model. The City of Cape Town (2019) water use calculator appears to notably under-estimate the water use, especially for the ABC. The lack of specificity in the water use calculator may be a contributing factor to the underestimation of water use. There are several smaller water use activities that the City of Cape Town's water use calculator does not make provision for. As with a series of small monetary payments that add up to a surprisingly large amount of money; adding up the small missed water use activities could account for the difference between the results of the LCD model and the water use calculator. The LCD model makes provision for the following water use activities, and the volumes thereof, which The City of Cape Town's water use calculator does not:

- Bath (if showers are not available) ~ 10 L/c/d
- Eyecare ~ 2 L/c/d
- Cleaning of kitchen counter ~ 4 L/c/d
- Cooking water beyond that needed for washing fruit and vegetables ~ 5 L/c/d
- Water for pets besides cats and dogs ~ 2 L/c/d
- Miscellaneous water use activities ~ 0.75 L/c/d

The results determined by the SFWMD water use calculator were 106 L/c/d, 155 L/c/d, 461 L/c/d and 1018 L/c/d for the ABC, REAL, esteemed needs and ultimate consumption lifestyle levels, respectively. The results of the ABC and REAL lifestyle level are comparable to the results of the LCD model. The indoor water use modelled in the LCD model is, therefore, comparable to the indoor water use found to be common in Southwest Florida. However, the water use for the esteemed needs and ultimate consumption lifestyle levels were 103% and 224% greater than the results found by the LCD model. Florida is a warm area with summer temperatures averaging between 31° and 33° (Climates to Travel, 2019). The warmer summer temperatures and outdoor lifestyle of Florida could contribute to a proportionally higher outdoor water use than what was modelled in the LCD model.

Table 8.1: Expected water use according to the SFWMD water calculator

Water Use Activity	ABC Lifestyle Level	Resultant water use (L/c/d)	REAL Lifestyle Level	Resultant water use (L/c/d)
Body washing	2-minute shower	20.0	6-minute showers	60.0
Toilet	2 x full flush	18.0	2 x full flush 3 x half flush	31.5
Hygiene	8 x hand washing	2.4	12 x hand washing	3.6
	1 x face washing	0.5	2 x face washing	1.0
Brushing teeth	2 x brushing teeth	0.3	2 x brushing teeth	0.3
Laundry	1 x load per week	10.0	3 loads per week	30.0
Dishes	3 x dishwasher loads per week 1 x sink wash per week	11.6	3 x dishwasher loads per week 1 x sink wash per week	11.6
Drinking	1 x 3 L water, tea or coffee	3.0	1 x 3 L water, tea or coffee	3.0
Cooking	1 x washing veg	2.0	1 x washing veg	2.0
House Cleaning	1 x house cleaning per week	1.1	2 x house cleaning per week	2.3
Pets	1 x 3 kg cat 1 x 20 kg dog	1.5	1 x 3 kg cat 1 x 20 kg dog	1.5
		70.4		**146.8**

Table 8.2: Expected water use according to the City of Cape Town's water calculator

Water Use Activity	ABC Lifestyle Level	Resultant water use (L/c/d)	REAL Lifestyle Level	Resultant water use (L/c/d)	Esteemed Needs Lifestyle Level	Resultant water use (L/c/d)	Ultimate Consumption Lifestyle Level	Resultant water use (L/c/d)
Shower	1 x 3-minute shower ✓ low flow showerhead	22.7	1 x 7-minute shower ✓ low flow showerhead	53.0	1 x 7-minute shower ✓ low flow showerhead	53.0	1 x 7-minute shower ✓ low flow showerhead	53.0
Bath	0 x baths	0.0	0 x baths	0.0	1 x baths	18.9	1 x baths	18.9
Toilet flushes	2 x toilet flushes ✓ dual flush	11.4	5 x toilet flushes ✓ dual flush	30.3	5 x toilet flushes ✓ dual flush	30.3	5 x toilet flushes ✓ dual flush	30.3
Running water	5 minutes per day ✓ low flow tap	30.0	5 minutes per day ✓ low flow tap	30.0	5 minutes per day ✓ low flow tap	30.0	5 minutes per day ✓ low flow tap	30.0
Hand washing Dishes	3 minutes per day ✓ low flow tap	18.9	3 minutes per day ✓ low flow tap	18.9	3 minutes per day ✓ low flow tap	18.9	3 minutes per day ✓ low flow tap	18.9
Dishwasher	3 x loads per week	7.6	3 x loads per week	7.6	3 x loads per week	7.6	3 x loads per week	7.6
Laundry	1 x load per week ✓ water-saving machine	15.0	2 x load per week ✓ water-saving machine	15.0	2 x load per week ✓ water-saving machine	15.0	2 x load per week ✓ water-saving machine	15.0

Lawn watering	No outdoor use	0.0	No outdoor use	0.0	2 x 15-minute irrigation cycles per week	249.8	2 x 45-minute irrigation cycles per week	745.7
Outside water	No outdoor use	0.0	No outdoor use	0.0	3 minutes of outdoor water use	15.1	10 minutes of outdoor water use	49.2
Pool	No outdoor use	0.0	No outdoor use	0.0	5 minutes of filling the pool	22.7	10 minutes of filling the pool	49.2
		105.6		**154.8**		**461.3**		**1017.8**

8.2 Customising model results for different household sizes

The model results were adjusted for different household sizes using Equation 3.1. Household size was restricted to a maximum of five people per household. The results for each lifestyle level are summarised in Table 8.3 and presented graphically in Figure 8.2. The ABC results for a household size greater than 2 PPH fell with the yard tap connection water use range given by DHS (2019) and above the minimum water requirements for living stipulated by WHO (2003) and Gleick (1996), of 20 to 50 L/c/d. The results illustrated how per capita water use could be adjusted for different household sizes. A five-person household uses approximately 50% less water per capita per day than a single-person household. The reduction is due to the shared water use activities, including but not limited to clothes washing, dishwashing, house cleaning, irrigation and swimming pool use. The reduction in per capita water use with increased household size was assumed to follow the same trend for all lifestyle levels. The LCD model could be improved, given more accurate input information, by describing each input and lifestyle level separately – this would require approximately 300 additional input variables.

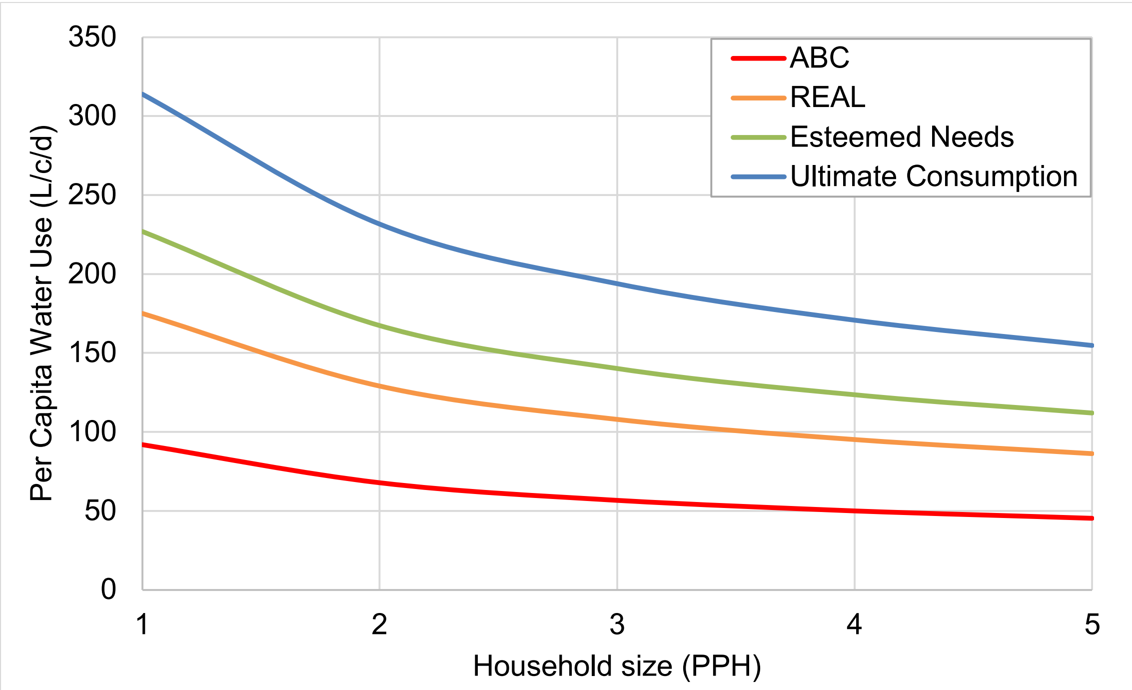

Figure 8.2: Per capita water use adjusted for household size

Table 8.3: Per capita consumption for increasing household size

	Per capita water use (L/c/d)				
Lifestyle level/PPH	**1**	**2**	**3**	**4**	**5**
ABC	92	68	57	50	45
REAL	175	129	108	95	86
Esteemed Needs	227	167	140	124	112
Ultimate Consumption	314	232	194	171	155

9 Conclusion

9.1 Key findings

The question has been raised, especially considering the increased demand for water and the increasing prevalence of water scarcity in many countries, as to how much water a household needs to live a normal, healthy and sanitary life. In the past, the question was answered by looking at local municipal water use. However, alternative sources are becoming more common in households and therefore metered municipal water use values may not be a true representation of actual water use. Additionally, actual water use may not be an accurate measure of how much water a household should ideally be using, as many households may use more water than they need for the normal running of the household. Therefore, an alternative means to determine an ideal household water use needed to be developed.

A stochastic model, entitled the litre per capita per day (LCD) model, was developed to estimate the domestic per capita water requirements for a single person, fully serviced, urban household at different lifestyle levels. Maslow's (1943) hierarchy of needs was used as a basis from which the needs for each lifestyle level were developed. Firstly, the ultimate consumption lifestyle was modelled. The ultimate consumption lifestyle included water use without any restrictions. Both indoor and outdoor water use was modelled according to a "typical" urban household, based on unrestricted values found in literature. Thereafter restrictions were placed on the ultimate consumption lifestyle level in accordance with the requirements for each lifestyle level. The second lifestyle level modelled was the esteemed needs lifestyle level, which aimed to model unrestricted indoor use and outdoor use under moderate water restrictions (eg. level 3 water restrictions implemented by The City of Cape Town and stage 4 water restrictions bylaws set out the by Western Australia Water Agency). The third lifestyle level modelled was the REAL consumption. Lastly, the absolute minimum water required for a human to live, with only meeting the lower bound of any recommendations and without any extra luxurious activities, was determined. The absolute minimum lifestyle's level water requirements were referred to as the ABC. The ABC values are not ideal values for living a normal life as they are extreme minimums and will be hard to obtain and maintain for an extended period of time.

The LCD model produced a distribution of expected water use for each lifestyle level. The results show that providing for all health and sanitary requirements expected in a, urban household, the basic water requirement is on average 92 L/c/d. On the other extreme, providing for unrestricted indoor and outdoor water requires an average of 314 L/c/d. The results of the LCD model were comparable to per capita water use values found in literature.

However, the water use calculators developed by the City of Cape Town and the Southwest Florida Water Management District provided water use estimations lower than the LCD model for the ABC and REAL lifestyle level due to a lack of specificity resulting in a number of small water uses being omitted. The water calculators produced higher results than the LCD model for the esteemed needs and ultimate consumption lifestyle level.

This research can be used by water authorities to realistically set water limits for water restrictions, as well as for planning future developments. Once realistic domestic water requirements are known, the distribution of water resources amongst the different water sectors can be conducted with greater knowledge, thus leading to more efficient distribution of water. The LCD model included water used for domestic purposes, both inside and outside of the household space, including water used, for example, at gym or at work. Should water use be planned for in these non-residential spaces, that fraction of water use can be excluded from the model results. However, the model results give a quick holistic view of all the water requirements for a single person that need to be provided for.

9.2 Further research needs

The following recommendations for further studies can be made:

- Adjust the model to be more specific to different regions of the world as the water use habits and appliances around the world differ. A region-specific model would be more accurate as cultural, behavioural and environmental considerations should be included for better accuracy (Willis et al., 2013; Jorgensen et al., 2009). Countries with more modern technology may use less water in toilets whereas countries with older houses will have old toilets with mostly 9 L or even 12 to 25 L cisterns. Washing machines differ significantly between countries. Australia and Europe have more front-end loaders while North America have more top-end loaders, which use different volumes of water. Climate plays a significant role in outdoor water use, different countries and even different regions within a country have vastly different climates which mean irrigation and pool use will differ significantly. Property sizes vary in countries as does garden size, which will affect outdoor water use. Household size also varies both in physical size and in occupancy rate which will affect household washing, clothes washing, dishwashing et cetera. These factors can only be considered when the model is customised to a specific area.
- The LCD Model is currently a static model set up with generalisations based on international literature. Therefore, no user inputs can be given to dynamically modify the model for a specific region or household. An investigation should be done into

modifying the model such that a user can input their own specifications. Allowing user input will eliminate several uncertainties, such as type of water use appliances and duration of use, resulting in more accurate water use behaviour being modelled. A specialised model will allow users to determine their expected water use and compare it to the norms, other users or their local restrictions.

- The model was developed for a western, urban, fully serviced household. Modifications can be made to the model to model the differences found in countries that have households with differing amenities to those modelled in this study, such as non-flushing toilets or communal baths.
- Only domestic water use was considered for this study. Typical water use includes commercial, industrial and institutional water use. Further research could consider including all aspects of water use that would have to be provided for by water providers.
- The use of alternative water sources to reduce demand on water providers was not considered in this study. However, many households make use of one or more forms of alternative water sources. It would be beneficial to investigate the presence of alternative water sources and the effect it would have on the demand on water providers. Therefore, modelling alternative water sources into the LCD could prove useful when planning for actual water use.
- The LCD model was not developed with data of the most modern technology. The LCD model is a general model that is representative of any urban household's water use. As a result, a range of water use technologies will be expected. Therefore, the model aimed to represent the age range of technologies by including data from 2000 to 2019. The model can be modified to include only the most current water use technology. However, including only the most modern technology could prove troublesome as water use technologies are constantly developing resulting in constant maintenance of the model being required.
- Further work is needed to include income and other socio-economic factors into the calculation of per capita consumption with regards to household size. Including other socio-economic factors could allow for a scaling factor which could accommodate property size and price elasticity etc. into the per capita consumption calculations.
- The model should be adjusted and rerun taking into consideration different household sizes and the effect on each water use activity.

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Appendix A – Per capita water use values

Table A 1: Summary of literature per capita water use values

Citation	Data date	Country	Location	Micro/ Macro	Level of service	Reported water use (L/c/d)	PPH	Type of study	No. of households	Restrictions (Yes/No)
Jacobs and Haarhoff (2004a)	2004	South Africa	Johannesburg	Macro	Full house connection (indoor and outdoor)	326	3.00	Model		No
		South Africa	Cape Town			352				
		South Africa	George			246				
		Namibia	Windhoek			425				
Du Plessis (2007)	2002-2003	South Africa	Kliprand	Macro	Mixed	25		Empirical study		Yes - permanent restrictions
			Vredenburg			97				No
			Hermon			98				
			Riebeek West			98				
			Raithby			103				
			Rietpoort			112				
			Riebeek Kasteel			113				
			Nuwerus			132				
			Bitterfontein			135				
			Paternoster			144				
			Pniel			146				
			Hopefield			147				
			Eendekuil			157				
			Aurora			160				
			Kylemore			170				
			Abbotsdale			173				
			Chatsworth			173				

Citation	Data date	Country	Location	Micro/ Macro	Level of service	Reported water use (L/c/d)	PPH	Type of study	No. of households	Restrictions (Yes/No)
Du Plessis (2007)	2002-2003	South Africa	Gouda	Macro	Mixed	175		Empirical study		No
			Koringberg			177				
			Piketberg			178				
			Kalbaskraal			178				
			Darling			181				
			Riverland			182				
			Elandsbay			194				
			Lutzville			195				
			Moorreesburg			195				
			Clanwilliam			200				
			Saldanha			201				
			Koekenaap			206				
			Klapmuts			213				
			Ebenhaezer			218				
			Velddrif			220				
			Tulbagh			222				
			Vanrhynsdorp			226				
			Calvinia			244				
			Strandfontein			249				
			Goedverwacht			251				
			Doringbaai			252				
			Graafwater			262				
			Wittewater			264				
			Citrusdal			266				
			Wellington			275				
			Porterville			277				

Citation	Data date	Country	Location	Micro/ Macro	Level of service	Reported water use (L/c/d)	PPH	Type of study	No. of households	Restrictions (Yes/No)
Du Plessis (2007)	2002-2003	South Africa	Redelinghuys	Macro	Mixed	284		Empirical study		No
			Jamestown			287				
			Malmesbury			295				
			Saron			300				
			Franschoek			303				
			Paarl			321				
			Dwarskerbos			404				
			Klawer			407				
			Lambertsbay			409				
			St Helena Bay			429				
			Langebaan			442				
			Stellenbosch			445				
			Vredendal			497				
			Yzerfontein			952				
			Leipoldtville			1479				
Shaban and Sharma (2007)	2001	India	Delhi	Macro	Mixed - low cost to full house connections	78		Supply based estimate		No
			Mumbai			90				
			Kolkata			116				
			Hyderabad			96				
			Kanpur			77				
			Ahmedabad			95				
			Madurai			88				
Mayer et al. (1999)	1996	United States and Canada	Nationwide	Micro	Full house connection - outdoor	236	3.00	Empirical study	1188	No

Citation	Data date	Country	Location	Micro/ Macro	Level of service	Reported water use (L/c/d)	PPH	Type of study	No. of households	Restrictions (Yes/No)
Rathnayaka et al. (2014)	2003	Australia	Yarra Valley, Melboune	Micro	Full house connection - indoor and outdoor	238	3.02	Empirical study		Yes, stage 1
	2011				Full house connection - indoor and outdoor	124	3.16			
Sadr et al. (2016)	2015	India	Jaipur	Macro	Full house connection - indoor	183		Survey and empirical study		No
					Full house connection - outdoor	215				
Lee et al. (2012)	2002-2006	Korea	Nationwide	Micro	Full house connection - indoor	159		Empirical study	146	No
					Full house connection - outdoor	141				
DeOreo et al. (2011)	2007	United States	California	Micro	Full house connection - outdoor	204	3.00	Empirical study	780	No
DeOreo (2011)	2006-2008	United States	Arizona California Colorado Floria Nevada Oregon Utah	Micro	Full house connection - outdoor	167	3.00	Empirical study	240	No
Loh and Coghlan (2003)	1998-2001	Australia	Perth	Micro	Full house connection - outdoor	335		Empirical study	120	No
Mead (2008)	2008	Australia	Toowoomba	Micro	Full house connection - indoor	112		Empirical study	10	No
Sivakumaran and Aramaki (2010)	2004	Sri Lanka	Trincomalee	Micro	Limited household connection	139	4.70	Consumer survey	285	No
Hussien et al. (2016)	2015	Iraqi Kurdistan	Duhok	Micro	Full house connection - outdoor	274	7.04	Survey	407	No
					Full house connection - indoor	247				
Roberts (2005)	2004	Australia	Yarra Valley, Melboune	Micro	Full house connection - outdoor	226		Empirical study	100	No
					Full house connection - indoor	169				

Citation	Data date	Country	Location	Micro/ Macro	Level of service	Reported water use (L/c/d)	PPH	Type of study	No. of households	Restrictions (Yes/No)
Willis et al. (2013)	2008	Australia	Gold coast	Micro	Full house connection - outdoor	157		Empirical study	151	No
					Full house connection - indoor	139				
Smith (2010)	2005-2007	South Africa	Eastwood, Pietermaritzburg	Micro	Full house connection - outdoor	131		Empirical study	194	No
					Limited household connection	89	4.10		34	No
Thiel (2014)	2013	Netherlands	Amsterdam	Micro	Full house connection - indoor	119		Empirical study	1349	No
Athuraliya et al. (2012)	2012	Australia	Yarra Valley, Melboune	Micro	Full house connection - indoor	93	2.60	Empirical study	100	No
Athuraliya et al. (2012)	2010	Australia	Yarra Valley, Melboune	Micro	Full house connection - indoor	105	2.60	Empirical study	100	No
Jordán-Cuebas et al. (2018)	2011-2013	United states	New York	Micro	Full house connection - indoor	222		Empirical study	30	No
Lee et al. (2011)	2006-2009	USA	Miami-Dade County, Florida	Micro	Full house connection - outdoor	312,3	3.10	Metered data	1829	No
Manzunga and Machiridza (2005)	2003	Zimbabwe	Mabelreign	Micro	Limited household connection	226	6.00	Metered data collected through questionnaires	8	No
			Mt. Pleasant		Limited household connection	353	5.00		6	
			Marlborough		Limited household connection	167	8.00		4	
			Kuwadzana		Limited household connection	58	24.00		4	
			Glen Norah		Limited household connection	105	8.00		12	
			Budiriro		Limited household connection	108	9.00		10	
			Tafara		Limited household connection	69	10.00		6	
			Mabvuku		Limited household connection	29	10.00		4	

Citation	Data date	Country	Location	Micro/ Macro	Level of service	Reported water use (L/c/d)	PPH	Type of study	No. of households	Restrictions (Yes/No)
Hay et al. (2012)	2008	South Africa	Adelaide, Western Cape	Macro	Full house connection - outdoor	190		Meter data		No
			Bedford, Western Cape		Full house connection - outdoor	109				
			Alice, Eastern Cape		Full house connection - outdoor	193				
			Stutterheim, Eastern Cape		Full house connection - outdoor	245				
			Mthatha, Eastern Cape		Full house connection - outdoor	263				
			Tulbagh, Western Cape		Full house connection - outdoor	309				
			Beaufort West, Western Cape		Full house connection - outdoor	206				
			Ashton, Western Cape		Full house connection - outdoor	432				
			Plettenberg Bay, Western Cape		Full house connection - outdoor	281				
			Bitterfontein, Western Cape		Full house connection - outdoor	123				
Parker and Wilby (2013)	1992-2006	UK	East England Lincoln Ruthamford	Micro	Full house connection - indoor	169		Model	100	No
Rathnayaka et al. (2015)	2010	Australia	Yarra Valley City West	Micro	Full house connection - outdoor	113	3.10	Empirical study	117	Yes - Stage 1
	2012					115				Yes - Stage 2
Dias et al. (2018)	2015-2016	Brazil	Jointville	Micro	Full house connection - indoor	102		Empirical study	3171	No
Guragai et al. (2018)	2016	Nepal	Kathmandu Valley	Micro	Mixed – delivered tank water to full indoor house connections	56	6.40	Empirical study	28	Intermittent water supply

Appendix B – LCD Survey

Table B 1: LCD survey results

Dear prospective participant. The Department of Civil Engineering, Stellenbosch University, would like to encourage you to participate in this consumer survey. The survey should take about 10 minutes to complete. The research forms part of Master's studies to address domestic water use needs, while maintaining a healthy lifestyle. This survey has been approved by the Research Ethics Committee (REC) at Stellenbosch University and is conducted according to accepted and applicable national and international ethical principles. INTRODUCTION: Every human has a right to a minimum amount of water for survival. This minimum value includes water for drinking, food preparation, bathing and sanitation. However, it is unrealistic to expect people to live at a bare minimum, with only their basic physiological needs met. According to Maslow's Hierarchy of Needs, humans have different levels of needs. Therefore, the water requirements needed to meet these different levels of needs are being investigated. PURPOSE: The main purpose of this study is to determine household water requirements at different lifestyle levels. PROCEDURES: This study will use scientific data to determine the expected water use for identified end uses. An online survey will be conducted to verify lesser researched data. Your input in terms of your desired water use in your home will be required. RISKS: While there are no known risks with the research study, as with any online activity, the risk oa f breach is possible. Every attempt will be made to keep information confidential. BENEFITS: The benefits of participation include involvement in a topical and highly relevant field that will assist in reducing negative water-related impacts on society and the environment; and assist in improved management of the precious resource. PARTICIPATION and WITHDRAWAL: You have the right to withdraw from this survey at any point without any penalty. All data recorded prior to your exiting will be deleted from the database. CONFIDENTIALITY: No personal information that could identify the participant will be required. DATA STORAGE: Raw data will be stored in the Survey Monkey account which will be password protected, and analysed data will be stored in dropbox which is password protected. The researchers' laptops are password protected and will not be unattended without being locked or switched off. This survey is restricted to participants over the age of 18. If you have any questions or concerns about this research project, please feel free to contact Melissa Crouch, 18290213@sun.ac.za; 0798436886 (principal investigator) or Heinz Jacobs, hejacobs@sun.ac.za; 021 808 4059 RIGHTS OF RESEARCH PARTICIPANTS: You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact Ms Malene Fouche (mfouche@sun.ac.za/0218084622) at the Division for Research Development.

I have read the above information and it is written in a language in which I am fluent and comfortable	100.0%
I confirm that I am over 18 years old	100.0%
I understand that taking part in this study is voluntary and I have not been pressurised to take part	100.0%
I understand that I may choose to leave the study at any time and will not be penalised or prejudiced in any way	100.0%
All issues related to privacy and the confidentiality and use of the information I provide have been explained to my satisfaction	100.0%
I have read the above information and it is written in a language in which I am fluent and comfortable	100.0%
This study involves occupants of a dwelling that have a constant supply of drinking water to the household. Confirm that you fall into this category?	
Yes	100.0%
No	0.0%
We regularly experience supply interruptions (more than once per week)	0.0%
Gender	
Male	43.7%
Female	54.5%
Prefer not to say	1.8%
Age Category	
18-35	64.1%
35-55	23.4%
55+	12.6%
Prefer not to say	0.0%

On average, how frequently do you feel a person has to bath or shower for hygienic purposes and cleaning? (A subsequent question addresses relaxation)		
	ABC	REAL
0	0.0%	0.0%
Once a week or less	8.2%	0.0%
Twice a week	13.3%	1.9%
Every second day	34.2%	12.9%
1 per day	42.4%	65.2%
2 per day	1.9%	20.0%

On average, how frequently do you feel a person has to bath or shower for relaxation, e.g. to reduce stress and maintain a healthy state of mind? (This would be in addition to the answer given above addressing hygiene/cleaning)		
	ABC	REAL
0	40.9%	21.2%
Once a week or less	24.5%	34.0%
Twice a week	7.6%	9.0%
Every second day	8.8%	5.1%
1 per day	13.2%	18.6%
2 per day	5.0%	12.2%
On average, how frequently do you feel a person has to brush their teeth?		
	ABC	REAL
0 per day (eg. Use dentures)	1.3%	0.0%
1 per day	41.5%	8.4%
2 per day	54.1%	81.9%
3 per day	2.5%	9.0%
4 per day	0.6%	0.7%
On average, how frequently do you feel a person has to use shampoo and/or conditioner to wash their hair?		
	ABC	REAL
0	2.5%	1.3%
Once a week or less	33.8%	11.5%
About twice a week	31.9%	28.7%
Every second day	25.0%	33.1%
1 per day	6.3%	24.2%
2 per day	0.6%	1.3%
On average, how frequently do you feel a person has to shave, using water? (This does not include other hair removal methods, such as, an electric razor, waxing, laser hair removal, or epilation)		
	ABC	REAL
0	29.6%	16.0%
Once a week or less	42.8%	30.1%
About twice a week	17.6%	32.1%
1 per day	10.1%	21.2%
2 per day	0.0%	0.6%

On average, how frequently do you think a house (floors, counters and bathrooms) needs to be cleaned with water - by a cleaning service, a domestic worker, or by cleaning it yourself?		
	ABC	REAL
Once a month or less	37.7%	12.2%
Once a week	40.9%	46.8%
About twice a week	16.4%	27.6%
1 per day	5.0%	13.5%
On average, how frequently do you feel a person has to wash their house windows?		
	ABC	REAL
Once a month or less	93.0%	76.9%
About every second week	7.1%	21.2%
Once a week	0.0%	1.9%
About twice a week	0.0%	0.0%
On average, how frequently do you feel a person has to wash their bedding and linen, assuming everyday use of the bed/s?		
	ABC	REAL
About once a month	38.1%	15.3%
About every second week	41.9%	38.2%
Once a week	20.0%	44.6%
About twice a week	0.0%	1.9%
Do you wear glasses or contact lenses?		
Yes		55.0%
No		45.0%
Do you own pets?		
Yes		51.6%
No		48.5%

How many of each of the following pets do you own?						
	0	1	2	3	4	≥5
Birds in a cage (only give the number of bird cages)	89.6%	7.8%	1.3%	0.0%	0.0%	1.3%
Birds in a large aviary (only give the number of aviaries)	92.1%	5.3%	1.3%	0.0%	1.3%	0.0%
Cats	50.0%	26.9%	19.2%	3.9%	0.0%	0.0%
Dogs	28.1%	23.2%	40.2%	6.1%	2.4%	0.0%
Hamsters or rodents (only give the number of cages)	90.8%	7.9%	1.3%	0.0%	0.0%	0.0%
Indoor aquarium (only give the number of indoor aquariums)	89.6%	7.8%	2.6%	0.0%	0.0%	0.0%
Outdoor pond with fish (only give the number of outdoor ponds)	92.1%	6.6%	0.0%	0.0%	0.0%	1.3%
Reptiles (only the give the number of reptile enclosures)	97.4%	2.6%	0.0%	0.0%	0.0%	0.0%

In view of your answer regarding your water use, given above, we would like to know some further information. Do any of the following factors contribute to your recorded responses?			
	Yes	No	Prefer not to say
Do you have a job that requires above normal water use (e.g. having to wash your hands, body or clothes before or after entering a sterile or hazardous environment)?	13.2%	86.2%	0.6%
Do you strive to maintain a lifestyle where you exercise regularly, either outdoors or at a gym? (where exercise is having an elevated heart rate for more than 30 minutes)	72.3%	27.7%	0.0%
Are your water use habits influence by a religious practice or a medical condition?	1.9%	98.1%	0.0%

Consider Maslow's Hierarchy of Needs and how it could be linked to different levels of water use. The following table defines the different levels in Maslow's Hierarchy of Needs and the associated levels of water use:		
Maslow's Level	*Indoor water use*	*Outdoor water use*
Physiological Needs	Minimum water for survival, provided at a communal standpipe	No outdoor use
Safety Needs	The minimum amount of indoor water needed to live a healthy life	No outdoor use
Belongingness and Love Needs	Indoor water used to live a comfortable and healthy life	No outdoor use
Esteem Needs	Indoor water used to live a comfortable and healthy life, including watering of some indoor pot plants	Minimum outdoor use - used for small gardens and regulated pool and car/sports equipment washing
Self-actualisation	Unrestricted indoor use for comfortable living and extra luxuries, such as indoor plants, large baths for relaxation et cetera.	Unrestricted outdoor use for luxuries, such as a landscaped garden with ponds, pool, hot tub, and car/sports equipment washing

Which level best describes your current lifestyle?	
Physiological Needs	2.6%
Safety Needs	7.2%
Belongingness and Love Needs	24.3%
Esteem Needs	48.7%
Self-actualisation	17.1%
At which level do you desire to be?	
Physiological Needs	4.5%
Safety Needs	9.6%
Belongingness and Love Needs	19.2%
Esteem Needs	36.5%
Self-actualisation	30.1%

Appendix C – Model parameter distributions

Table C 1: Parameter distributions used for the ultimate consumption lifestyle level

	Parameter	Unit	Dist.[1]	μ	σ	Min	Max	Reference
Toilet	Flush frequency	flushes/c/d	PO	5.00		2.00		Roberts (2005); Rosenberg (2007); Mayer et al. (1999); DeOreo (2011); Hussien et al. (2016)
	Volume of 9 L single	L/flush	FV	9.00				Blokker et al. (2010)
	Volume of small flush 4.5/9 L Dual	L/flush	FV	4.50				Blokker et al. (2010)
	Volume of large flush 4.5/9 L Dual	L/flush	FV	9.00				Blokker et al. (2010)
	Volume of 6 L single	L/flush	FV	6.00				Blokker et al. (2010)
	Volume of small flush 3/6 L Dual	L/flush	FV	3.00				Blokker et al. (2010)
	Volume of large flush 3/6 L Dual	L/flush	FV	6.00				Blokker et al. (2010)
	Volume of small flush 2,5/4 L Dual	L/flush	FV	2.50				Gleick et al. (2003)
	Volume of large flush 2,5/4 L Dual	L/flush	FV	4.00				Gleick et al. (2003)
	Penetration rate of toilet type	%	DC[A]					Blokker et al. (2010)
	Full flush to half flush ratio	fraction of flushes	UN			0.40	0.60	Roberts (2005)
Shower	Percentage occurrence	%	BN	0.86				Browne et al. (2014); Matos et al. (2013)
	Penetration rate of low flow showerheads	%	BN	0.55				Grafton et al. (2011)
	Normal shower head flow rate	L/s	UN			0.10	0.33	Rosenberg (2007); Blokker et al. (2010); Hussien et al. (2016)
	Low flow shower head flow rate	L/s	UN			0.10	0.15	Rosenberg (2007); Blokker et al. (2010)
	Shower duration	s	LN	426.00	228.00			Roberts (2005); Blokker et al. (2010); DeOreo et al. (2011); Hand (2005)
	Shower frequency	showers/c/d	LN	0.85	0.49			Roberts (2005); Athuraliya et al. (2012)

Bath	Percentage occurrence for cleaning	%	BN	0.14				Browne et al. (2014); Matos et al. (2013)
	Frequency of bath for cleaning	baths/c/d	LN	0.85	0.49			Roberts (2005)
	Percentage occurrence for relaxation	%	BN	0.37				Blokker et al. (2010)
	Frequency of bath for relaxation	baths/c/d	PO	0.04				Blokker et al. (2010)
	Volume of bath	L/bath	UN			80.00	150.00	Hand et al. (2005); Roberts (2005); Blokker (2010); Hussien et al. (2016); Grafton et al. (2011)
Clothes Washing	Frequency of clothes washing	washes/c/d	NM	0.31	0.11	0.07	0.43	Roberts (2005); Buchberger et al. (1995); DeOreo et al. (2001); Blokker et al. (2010); Pakula and Stamminger (2010)
	Penetration rate of top-end loader	%	BN	0.37				Botha et al. (2018)
	Volume of top-end loader	L/wash	DC[B]					Table 5.2
	Volume of front-end loader	L/wash	DC[C]					Table 5.2
Dishwashing - automatic	Penetration rate of dishwashers	%	BN	0.53				Blokker et al. (2010); Gleick, (2003); Vinogradova et al. (2012)
	Frequency of dishwasher use	washes/c/d	UN			0.25	0.30	Roberts (2005); Blokker et al. (2010)
	Volume of dishwasher event	L/wash	DC[D]					Table 5.3
	Percentage occurrence of pre-rinse	%	BN	0.40				Richter (2011); Vinogradova et al. (2012)
	Volume of pre-rinse	L/pre-rinse	TR	5.00		3.00	7.00	Richter (2011)
Drinking Water	Volume of drinking water	L/c/d	LN	2.00	0.75	0.25		WHO (2003)
Dishwashing – by hand	Frequency of hand washing dishes - non dishwasher owners	washes/c/d	DC[E]					Berkholz et al. (2010)
	Frequency of hand washing dishes - dishwasher owners	washes/c/d	DC[E]					Berkholz et al. (2010)
	Volume of hand washing dishes	L/wash	TR	8.00		4.00	11.00	Berkholz et al. (2010)

Cooking	Volume of cooking water	L/event/d	UN			0.00	1.60	Thompson et al. (2001); Gleick (1996); Hussien et al. (2016)
Hand washing	Frequency of food preparation	events/c/d	PO	1.00		0.50	3.00	Engineering estimate
	Frequency of eating	events/c/d	PO	3.00		1.00	6.00	Kant (2018); Kerver et al. (2006)
	Frequency of handling pets	events/c/d	PO	2.00				Engineering estimate
	Frequency of miscellaneous hand washing	events/c/d	PO	1.50				Engineering estimate
	Hand washing duration	s	LN	10.00	5.00			Centre for Disease Control and Prevention (2016); WHO (2009)
	Hand washing flow rate	L/s	UN			0.08	0.33	Blokker et al. (2010); Rosenberg (2007)
Shaving	Percentage men to women	%	BN	0.51				WHO (2012)
	Percentage of men that shave	%	BN	0.79				LCD Model Survey
	Percentage of women that shave	%	BN	0.89				LCD Model Survey
	Frequency of men shaving using water	events/c/d	DC[F]					LCD Model Survey
	Frequency of women shaving using water	events/c/d	DC[F]					LCD Model Survey
	Volume of water used for shaving	L/event	UN			0.10	7.00	Matos et al. (2013)
Brushing Teeth	Frequency of teeth brushing	events/c/d	PO	2.00			4.00	LCD survey, American Dental Association (2019); Chestnutt (1998)
	Volume for teeth brushing	L/event	TR	0.50		0.25	1.50	Chestnutt (1998); Matos et al. (2013)
Cleaning House	Number of buckets used for house cleaning	buckets/wash	LN	2.00	0.50			Rosenberg (2007); Engineering estimate
	Volume of bucket	L/bucket	LN	6.00	2.00	1.00	10.00	Rosenberg (2007)
	Frequency of house cleaning	washes/c/d	DC[G]					LCD Model survey
Cleaning kitchen	Frequency = frequency of preparing food	events/c/d	PO	1.00		0.50	3.00	Engineering estimate
	Volume of wiping down counters	L/event	LN	1.00	0.50	0.00	2.00	Engineering estimate

Indoor Plants	Penetration rate of indoor plants	%	BN	0.45				Engineering estimate
	Volume of water for indoor plants	L/c/d	UN			0.25	2.00	Engineering estimate
Pets	Penetration rate of cats	%	BN	0.24				Table 5.6
	Number of cats	-	DC^H					LCD Model Survey
	Volume for cats - consumption	L/cat/d	UN			0.40	0.50	
	Volume for cats - cleaning	L/cat/d	UN			0.14	0.29	
	Penetration rate of dogs	%	BN	0.33				Table 5.6
	Number of dogs	-	DC^H					LCD Model Survey
	Volume for dogs - consumption	L/dog/d	UN			0.50	7.40	
	Volume for dogs - bathing	L/dog/d	UN			0.10	1.55	
	Penetration rate of birds in cages	%	BN	0.04				Table 5.6
	Number of birds in cages	-	DC^H					LCD Model Survey
	Volume for birds in cages - consumption	L/birds in cages/d	UN			0.30	1.80	
	Volume for birds in cages - bathing	L/birds in cages/d	UN			0.15	0.90	
	Volume for birds in cages - cleaning cage	L/birds in cages/d	UN			0.29	2.14	
	Penetration rate of birds in an aviary	%	BN	0.02				Table 5.6
	Number of birds in an aviary	-	DC^H					LCD Model Survey
	Volume for birds in an aviary - consumption	L/birds in aviary/d	UN			1.00	12.00	
	Volume for birds in an aviary - cleaning cage	L/birds in aviary/d	UN			0.71	1.57	
	Penetration rate of fish in an indoor aquarium/tank/bowl	%	BN	0.07				Table 5.6
	Number of in an indoor aquarium/tank/bowl	-	DC^H					LCD Model Survey
	Volume for fish in an indoor aquarium/tank/bowl	L/fish tank/d	UN			0.06	2.86	

Pets	Penetration rate of fish in an outdoor pond	%	BN	0.05				Table 5.6
	Number of fish in an outdoor pond	-	DC^{H}					LCD Model Survey
	Volume for fish in an outdoor pond - weekly maintenance	L/fishpond/d	UN			8.50	100.00	
	Volume for fish in an outdoor pond - seasonal maintenance	L/fishpond/d	UN			4.66	54.80	
	Penetration rate of reptiles	%	BN	0.02				Table 5.6
	Number of reptiles	-	DC^{H}					LCD Model Survey
	Volume for reptiles - consumption	L/reptiles/d	UN			0.14	0.53	
	Volume for reptiles - weekly cleaning	L/reptiles/d	UN			0.07	0.29	
	Volume for reptiles - monthly cleaning	L/reptiles/d	UN			0.17	0.33	
	Penetration rate of small animals	%	BN	0.02				Table 5.6
	Number of small animals	-	DC^{H}					LCD Model Survey
	Volume for small animals - consumption	L/ animal/d	UN			0.10	0.25	
	Volume for small animals - cleaning	L/animal/d	UN			0.29	1.57	
Irrigation	Irrigation season	weeks	UN			20.00	40.00	Roberts (2005); Rosenberg (2007)
	Penetration rate of water using garden	%	BN	0.63				Pullinger et al. (2013)
	Type of irrigation	-	DC^{I}					Roberts (2005)
	Frequency of use of handheld hose	events/c/d	TR	0.46		0.14	1.00	Roberts (2005); Hussien et al. (2016)
	Frequency of use of manual sprinkler	events/c/d	TR	0.47		0.14	1.00	
	Frequency of use of automatic sprinkler	events/c/d	TR	0.56		0.14	1.00	
	Frequency of use of other	events/c/d	TR	0.30		0.14	1.00	
	Flow rate of handheld hose	L/s	LN	0.25	0.05			Roberts (2005)
	Flow rate of manual sprinkler	L/s	LN	0.32	0.05			

	Flow rate of automatic sprinkler	L/s	LN	0.26	0.05			Roberts (2005)
	Flow rate of other	L/s	LN	0.26	0.05			
	Duration of handheld hose	s	LN	1500.00	300.00	300.00	3600.00	Roberts (2005)
	Duration of manual sprinkler	s	LN	4080.00	900.00	900.00	7200.00	
	Duration of automatic sprinkler	s	LN	3420.00	900.00	900.00	7200.00	
	Duration of other	s	LN	1680.00	300.00	300.00	3600.00	
Car Wash	Type of car wash	-	DC[J]					ICA (2017)
	Frequency of home wash	washes/c/d	DC[K]					Table 5.5; Hussien et al. (2016)
	Frequency of professional wash	washes/c/d	DC[K]					Table 5.5; Hussien et al. (2016)
	Volume of home wash	L/wash	UN			46.00	440.00	Rosenberg (2007); Smith and Shilley (2009); Janik and Kupiec (2007)
	Volume of professional wash	L/wash	UN			61.00	270.00	Janik and Kupiec (2007)
Leaks	Penetration rate of leaks	%	BN	0.17				Water Corporation (2010)
	Volume of leaks	L/c/d	UN			15.00	82.00	Liu et al. (2016); Mayer et al. (1999); Water Corporation (2010)
Swimming Pool	Countries with temperatures above 23˚C	%	FV	0.78				Trading Economics (2015)
	Countries that would have meet the penetration rate of SP	%	FV	0.60				Engineering estimate
	Presence of a swimming pool	%	BN	0.24				Water Resources Engineering, (2002); Rathnayaka et al. (2014); Fisher-Jeffes et al. (2014); Llausàs et al. (2018)
	Backwash and fill frequency	events/c/d	TR	0.03		0.01	0.14	Jacobs and Haarhoff (2004a); Fisher-Jeffes et al. (2014)
	Backwash and fill volume	L/event	LN	300.00	100.00	100.00	600.00	Jacobs and Haarhoff (2004a); Fisher-Jeffes et al. (2014)
Miscellaneous Activities	Volume of Cleaning Fridge	L/event	LN	1.00	0.50			Leverette (2019)
	Frequency of fridge clean	events/c/d	LN	0.01	0.01			Leverette (2019)
	Frequency of empty dishwasher run	events/c/d	LN	0.03	0.01			Leverette (2019)
	Frequency of empty washing machine run	events/c/d	LN	0.03	0.01			Leverette (2019)
	Frequency of window washing	events/year	TR	4.00	3.00	12.00		Rosengren (2014)

Miscellaneous Activities	Number of buckets used for window washing	buckets/event	PO	0.50		1.00		Engineering estimate
	Volume of bucket	L/bucket	LN	6.00	2.00	1.00	10.00	Rosenberg (2007)
	Percentage occurrence of eyecare	%	BN	0.61				CBS (2013)
	Frequency of eyecare	events/c/d	PO	2.25			3.00	Engineering estimate
	Volume of eyecare	L/event	LN	0.75	0.25			Engineering estimate
	Volume of other emergencies	L/event	UN			1.00	50.00	Engineering estimate
	Frequency of other emergencies	events/c/year	UN			1.00	52.00	Engineering estimate

1. LN = Lognormal; UN = Uniform; TR = Triangular; DC = Discrete; FV = Fixed Value (constant); PO = Poisson; BN = Binomial; NM = Normal

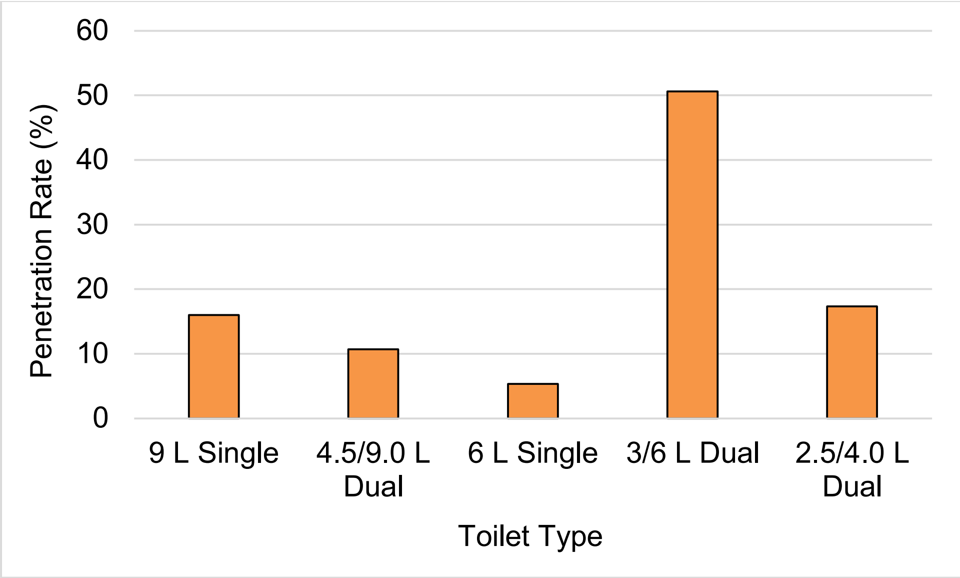

Figure C 1: A - Histogram of penetration rate of toilet type

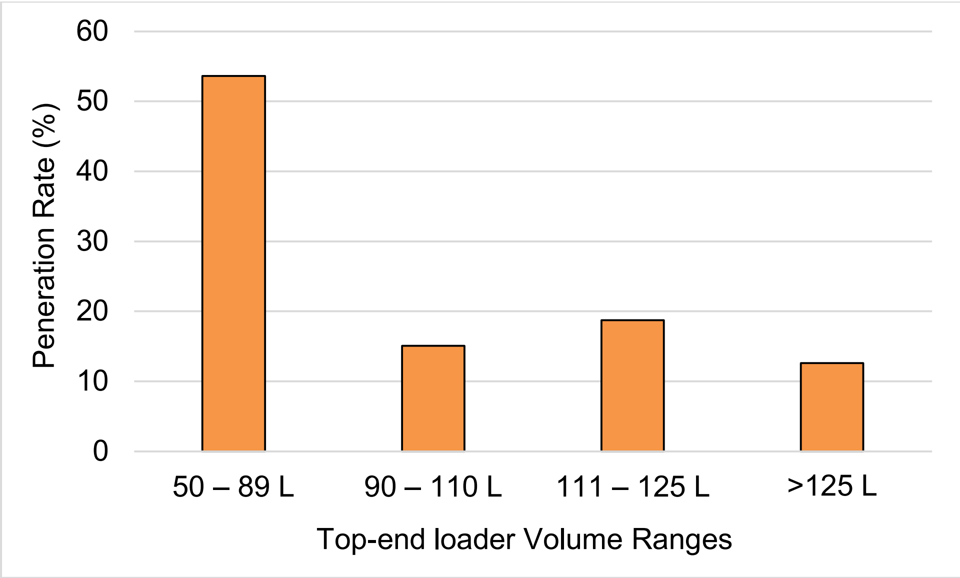

Figure C 2: B - Histogram of volume of top-end loader

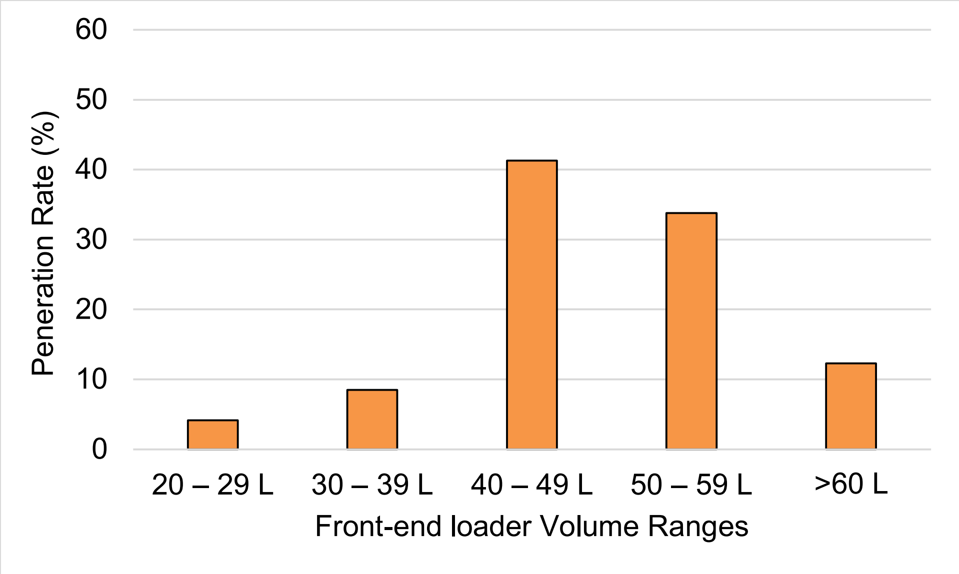

Figure C 3: C - Histogram of volume of front-end loader

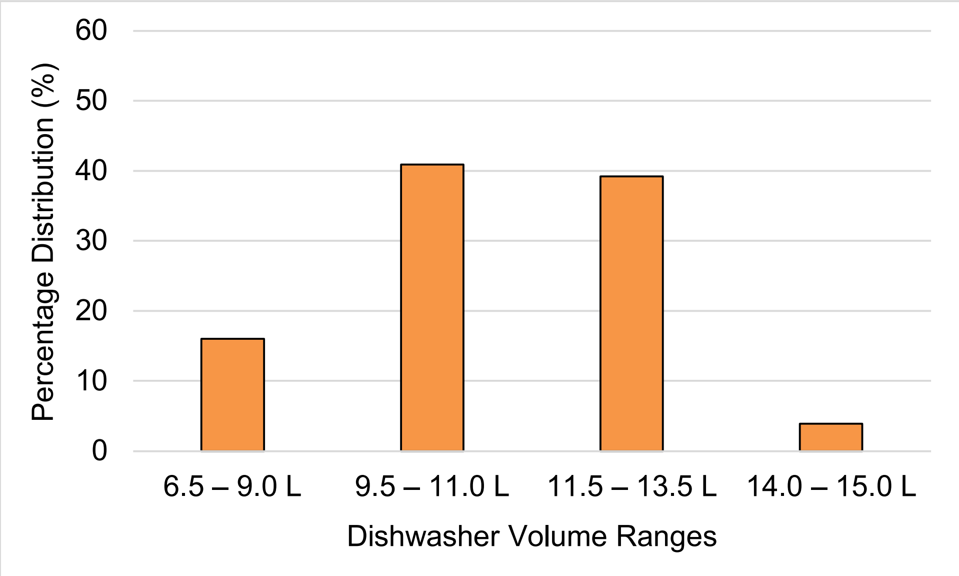

Figure C 4: D - Histogram of volume of dishwasher event

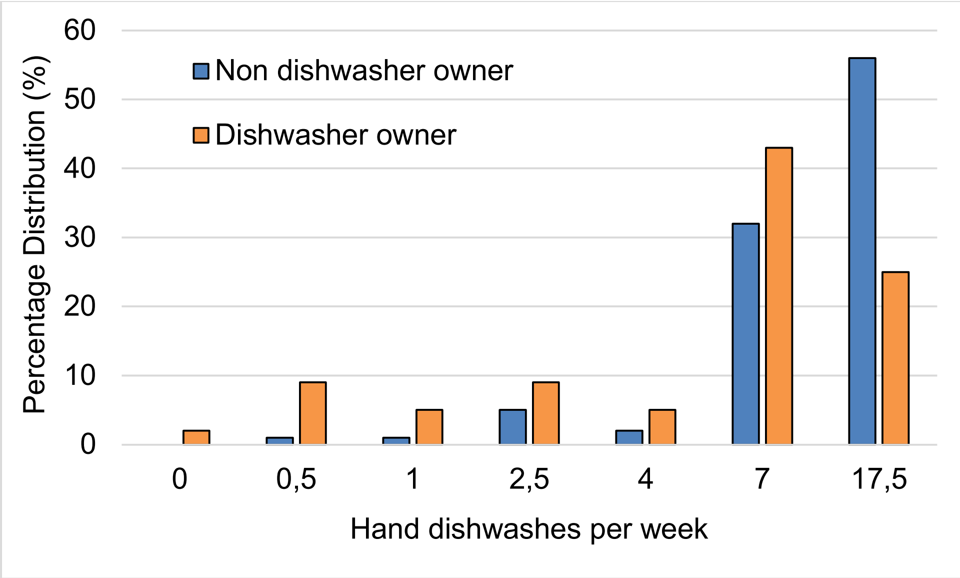

Figure C 5: E - Histogram of frequency of washing dishes by hand

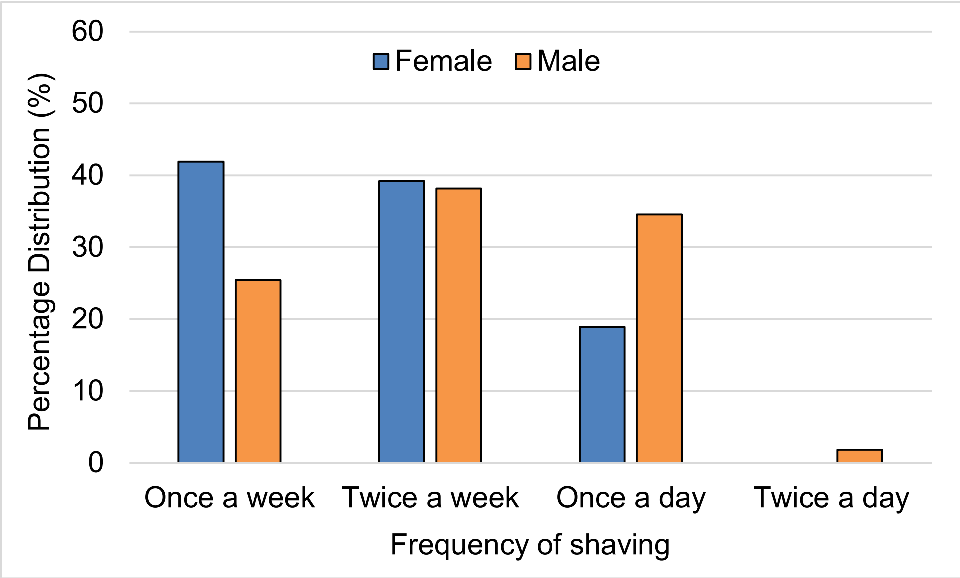

Figure C 6: F -Histogram of frequency of shaving with water

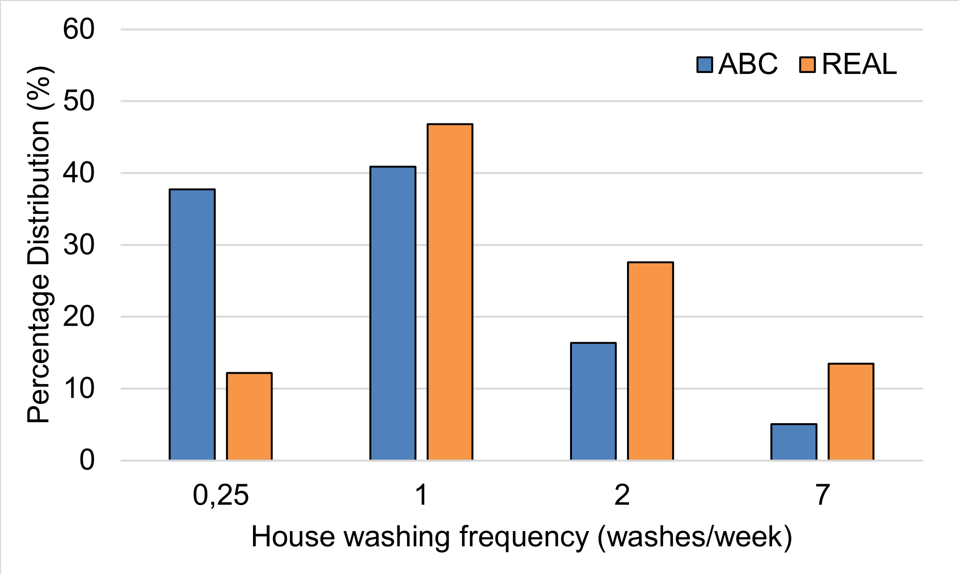

Figure C 7: G - Histogram of frequency of house cleaning

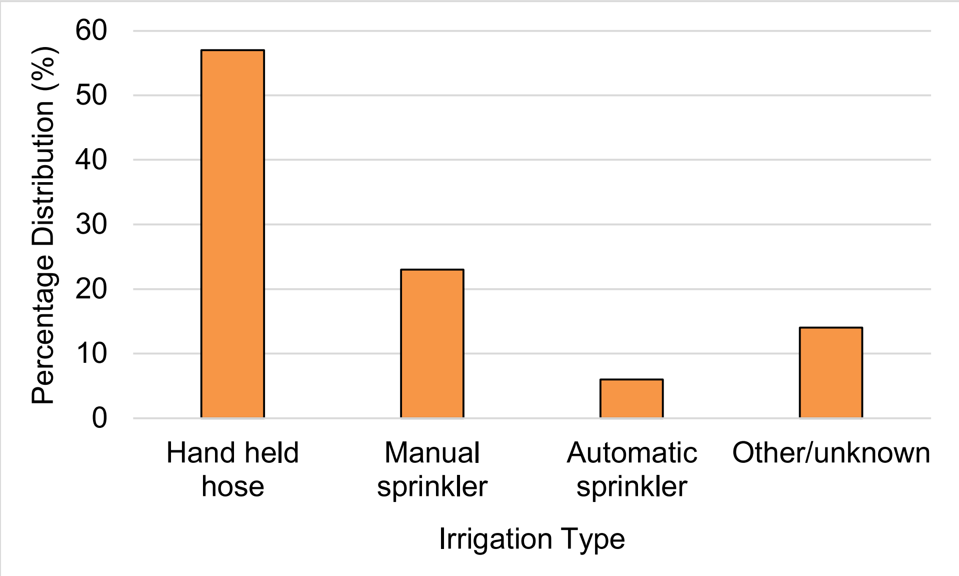

Figure C 8: I - Histogram of distribution of type of irrigation

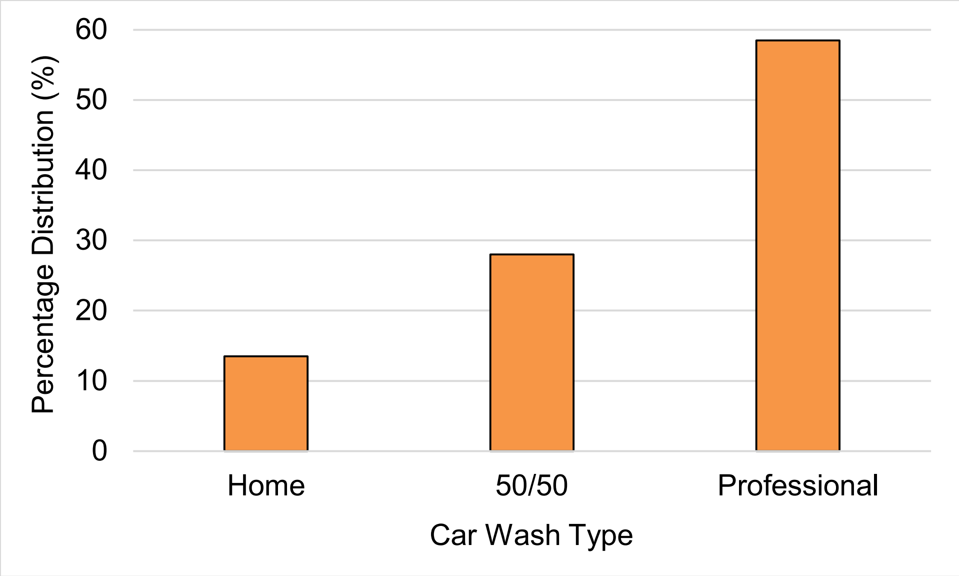

Figure C 9: J - Histogram of distribution of car wash type

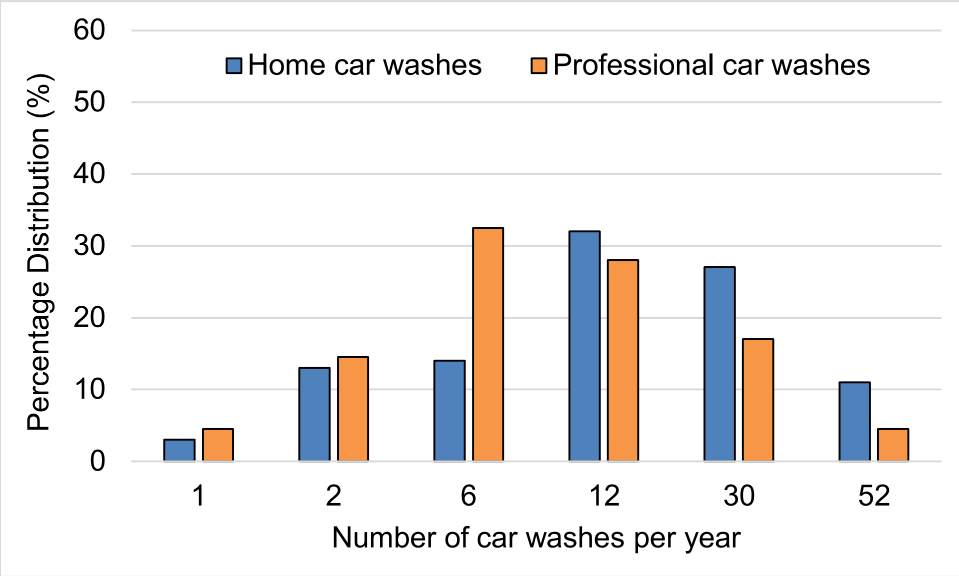

Figure C 10: K - Histogram of number of car washes per year

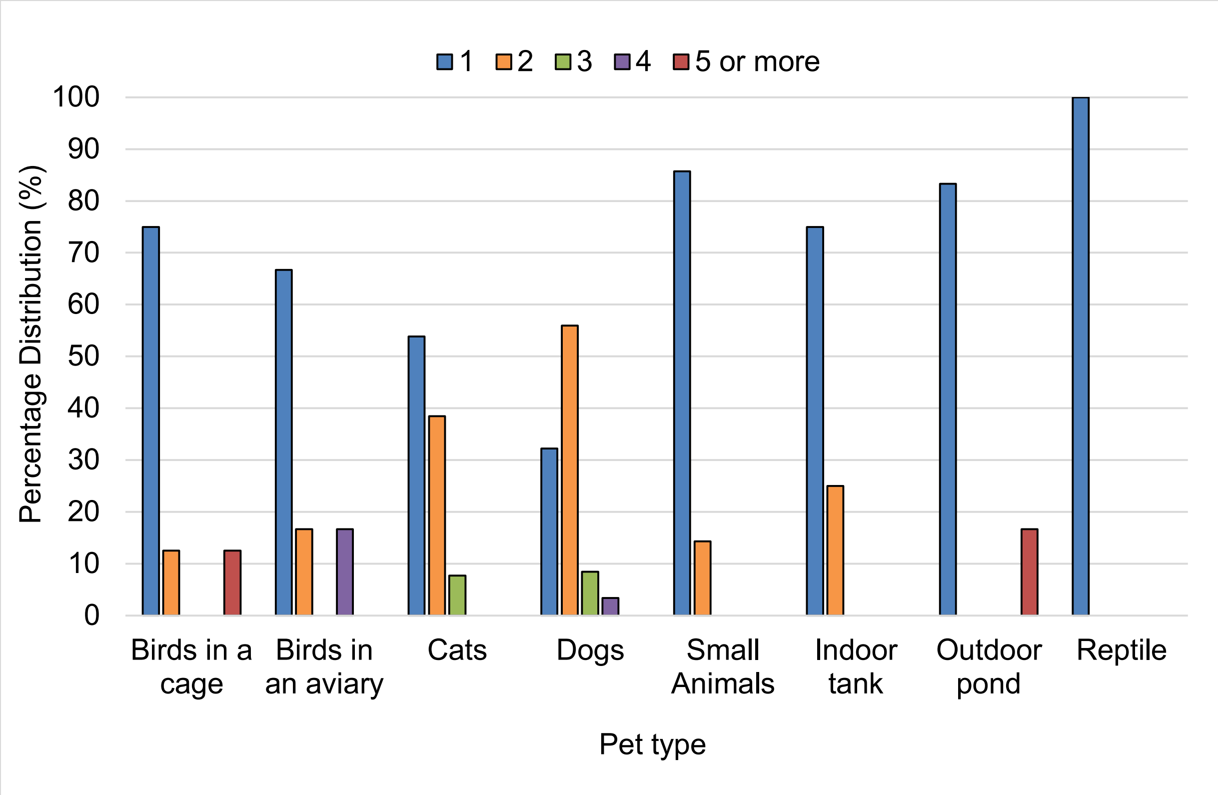

Figure C 11: H - Histogram of distribution of pets

Table C 2: Parameters modified from ultimate consumption for the esteemed needs lifestyle level

	Parameter	Unit	Dist.[1]	μ	σ	Min	Max	Reference
Irrigation	Frequency of use of handheld hose	events/c/d	TR	0.45		0.14	1.00	Roberts (2005); Hussien et al. (2016); The City of Cape Town (2019); Western Australia Water Agency (2017)
	Frequency of use of manual sprinkler	events/c/d	UN			0.07	0.29	
	Frequency of use of automatic sprinkler	events/c/d	UN			0.07	0.29	
	Frequency of use of other	events/c/d	UN			0.07	0.29	
	Duration of handheld hose	s	LN	900.00	300.00	300.00	3600.00	Roberts (2005); The City of Cape Town (2019); Western Australia Water Agency (2017)
	Duration of manual sprinkler	s	LN	2700.00	900.00	900.00	3600.00	
	Duration of automatic sprinkler	s	LN	2700.00	900.00	900.00	3600.00	
	Duration of other	s	LN	1680.00	300.00	300.00	3600.00	
Car Wash	Frequency of home wash	washes/c/d	DC[K]					Table 5.5; Hussien et al. (2016)
	Volume of home wash with bucket	L/wash	LN	22.00	11.00	11.00	44.00	Rosenberg (2007); Engineering estimate
Final swimming pool volumes were decreased by 50%								

Table C 3: Parameter distributions used for the REAL consumption lifestyle level

	Parameter	Unit	Dist.[1]	μ	σ	Min	Max	Reference
Toilet	Flush frequency	flushes/c/d	PO	5.00		2.00		Roberts (2005); Rosenberg (2007); DeOreo (2011); Hussien et al. (2016)
	Volume of 9 L single	L/flush	FV	9.00				Blokker et al. (2010)
	Volume of small flush 4.5/9 L Dual	L/flush	FV	4.50				Blokker et al. (2010)
	Volume of large flush 4.5/9 L Dual	L/flush	FV	9.00				Blokker et al. (2010)
	Volume of 6 L single	L/flush	FV	6.00				Blokker et al. (2010)
	Volume of small flush 3/6 L Dual	L/flush	FV	3.00				Blokker et al. (2010)
	Volume of large flush 3/6 L Dual	L/flush	FV	6.00				Blokker et al. (2010)
	Volume of small flush 2,5/4 L Dual	L/flush	FV	2.50				Gleick et al. (2003)
	Volume of large flush 2,5/4 L Dual	L/flush	FV	4.00				Gleick et al. (2003)
	Penetration rate of toilet type	%	DC[A]					Blokker et al. (2010)
	Full flush to half flush ratio	fraction of flushes	UN			0.40	0.60	Roberts (2005)
Shower	Percentage occurrence	%	BN	0.86				Browne et al. (2014); Matos et al. (2013)
	Penetration rate of low flow showerheads	%	BN	0.55				Grafton et al. (2011)
	Normal shower head flow rate	L/s	UN			0.10	0.33	Rosenberg (2007); Blokker et al. (2010); Hussien et al. (2016)
	Low flow shower head flow rate	L/s	UN			0.10	0.15	Rosenberg (2007); Blokker et al. (2010)
	Shower duration	s	LN	426.00	228.00			Roberts (2005); Blokker et al. (2010); DeOreo et al. (2011); Hand (2005)
	Shower frequency	showers/c/d	LN	0.85	0.49			Roberts (2005); Athuraliya et al. (2012)
Bath	Percentage occurrence for cleaning	%	BN	0.14				Browne et al. (2014); Matos et al. (2013)
	Frequency of bath for cleaning	baths/c/d	LN	0.85	0.49			Roberts (2005)
	Percentage occurrence for relaxation	%	BN	0.37				Blokker et al. (2010)
	Frequency of bath for relaxation	baths/c/d	PO	0.04				Blokker et al. (2010)
	Volume of bath	L/bath	UN			80.00	150.00	Hand et al. (2005); Blokker (2010); Hussien et al. (2016); Grafton et al. (2011)

Clothes Washing	Frequency of clothes washing	washes/c/d	NM	0.31	0.11	0.07	0.43	Roberts (2005); Buchberger et al. (1995); DeOreo et al. (2001); Blokker et al. (2010); Pakula and Stamminger (2010)
	Penetration rate of top-end loader	%	BN	0.37				Botha et al. (2018)
	Volume of top-end loader	L/wash	DC[B]					Table 5.2
	Volume of front-end loader	L/wash	DC[C]					Table 5.2
Dishwashing - automatic	Penetration rate of dishwashers	%	BN	0.53				Blokker et al. (2010); Gleick, (2003); Vinogradova et al. (2012)
	Frequency of dishwasher use	washes/c/d	UN			0.25	0.30	Roberts (2005); Blokker et al. (2010)
	Volume of dishwasher event	L/wash	DC[D]					Table 5.3
	Percentage occurrence of pre-rinse	%	BN	0.40				Richter (2011); Vinogradova et al. (2012)
	Volume of pre-rinse	L/pre-rinse	TR	5.00		3.00	7.00	Richter (2011)
Drinking Water	Volume of drinking water	L/c/d	LN	2.00	0.75	0.25		WHO (2003)
Dishwashing – by hand	Frequency of hand washing dishes - non dishwasher owners	washes/c/d	DC[E]					Berkholz et al. (2010)
	Frequency of hand washing dishes - dishwasher owners	washes/c/d	DC[E]					Berkholz et al. (2010)
	Volume of hand washing dishes	L/wash	TR	8.00		4.00	11.00	Berkholz et al. (2010)
Cooking	Volume of cooking water	L/event/d	UN			0.00	1.60	Thompson et al. (2001); Gleick (1996); Hussien et al. (2016)
Hand washing	Frequency of food preparation	events/c/d	PO	1.00		0.50	3.00	Engineering estimate
	Frequency of eating	events/c/d	PO	3.00		1.00	6.00	Kant (2018); Kerver et al. (2006)
	Frequency of handling pets	events/c/d	PO	2.00				Engineering estimate
	Frequency of misc. hand washing	events/c/d	PO	1.50				Engineering estimate
	Hand washing duration	s	LN	10.00	5.00			Centre for Disease Control and Prevention (2016); WHO (2009)
	Hand washing flow rate	L/s	UN			0.08	0.33	Blokker et al. (2010); Rosenberg (2007)

Shaving	Percentage men to women	%	BN	0.51				WHO (2012)
	Percentage of men that shave	%	BN	0.79				LCD Model Survey
	Percentage of women that shave	%	BN	0.89				LCD Model Survey
	Frequency of men shaving using water	events/c/d	DC[F]					LCD Model Survey
	Frequency of women shaving using water	events/c/d	DC[F]					LCD Model Survey
	Volume of water used for shaving	L/event	UN			0.10	7.00	Matos et al. (2013)
Brushing Teeth	Frequency of teeth brushing	events/c/d	PO	2.00			4.00	LCD survey, American Dental Association (2019); Chestnutt (1998)
	Volume for teeth brushing	L/event	TR	0.50		0.25	1.50	Chestnutt (1998); Matos et al. (2013)
Cleaning House	Number of buckets used for house cleaning	buckets/wash	LN	2.00	0.50			Rosenberg (2007); Engineering estimate
	Volume of bucket	L/bucket	LN	6.00	2.00	1.00	10.00	Rosenberg (2007)
	Frequency of house cleaning	washes/c/d	DC[G]					LCD Model survey
Cleaning kitchen	Frequency = frequency of preparing food	events/c/d	PO	1.00		0.50	3.00	Engineering estimate
	Volume of wiping down counters	L/event	LN	1.00	0.50	0.00	2.00	Engineering estimate
Indoor Plants	Penetration rate of indoor plants	%	BN	0.45				Engineering estimate
	Volume of water for indoor plants	L/c/d	UN			0.25	2.00	Engineering estimate
Pets	Penetration rate of cats	%	BN	0.24				Table 5.6
	Number of cats	-	DC[H]					LCD Model Survey
	Volume for cats - consumption	L/cat/d	UN			0.40	0.50	
	Volume for cats - cleaning	L/cat/d	UN			0.14	0.29	
	Penetration rate of dogs	%	BN	0.33				Table 5.6
	Number of dogs	-	DC[H]					LCD Model Survey
	Volume for dogs - consumption	L/dog/d	UN			0.50	7.40	
	Volume for dogs - bathing	L/dog/d	UN			0.10	1.55	

Pets	Penetration rate of birds in cages	%	BN	0.04				Table 5.6
	Number of birds in cages	-	DC^H					LCD Model Survey
	Volume for birds in cages - consumption	L/birds in cages/d	UN			0.30	1.80	
	Volume for birds in cages - bathing	L/birds in cages/d	UN			0.15	0.90	
	Volume for birds in cages - cleaning cage	L/birds in cages/d	UN			0.29	2.14	
	Penetration rate of birds in an aviary	%	BN	0.02				Table 5.6
	Number of birds in an aviary	-	DC^H					LCD Model Survey
	Volume for birds in an aviary - consumption	L/birds in aviary/d	UN			1.00	12.00	
	Volume for birds in an aviary - cleaning cage	L/birds in aviary/d	UN			0.71	1.57	
	Penetration rate of fish in an indoor aquarium/tank/bowl	%	BN	0.07				Table 5.6
	Number of in an indoor aquarium/tank/bowl	-	DC^H					LCD Model Survey
	Volume for fish in an indoor aquarium/tank/bowl	L/fish tank/d	UN			0.06	2.86	
	Penetration rate of fish in an outdoor pond	%	BN	0.05				Table 5.6
	Number of fish in an outdoor pond	-	DC^H					LCD Model Survey
	Volume for fish in an outdoor pond - weekly maintenance	L/fishpond/d	UN			8.50	100.00	
	Volume for fish in an outdoor pond - seasonal maintenance	L/fishpond/d	UN			4.66	54.80	
	Penetration rate of reptiles	%	BN	0.02				Table 5.6
	Number of reptiles	-	DC^H					LCD Model Survey
	Volume for reptiles - consumption	L/reptiles/d	UN			0.14	0.53	
	Volume for reptiles - weekly cleaning	L/reptiles/d	UN			0.07	0.29	

	Volume for reptiles - monthly cleaning	L/reptiles/d	UN			0.17	0.33	
	Penetration rate of small animals	%	BN	0.02				Table 5.6
	Number of small animals	-	DC[H]					LCD Model Survey
	Volume for small animals - consumption	L/ animal/d	UN			0.10	0.25	
	Volume for small animals - cleaning	L/animal/d	UN			0.29	1.57	
Miscellaneous Activities	Volume of Cleaning Fridge	L/event	LN	1.00	0.50			Leverette (2019)
	Frequency of fridge clean	events/c/d	LN	0.01	0.01			Leverette (2019)
	Frequency of empty dishwasher run	events/c/d	LN	0.03	0.01			Leverette (2019)
	Frequency of empty washing machine run	events/c/d	LN	0.03	0.01			Leverette (2019)
	Frequency of window washing	events/year	TR	4.00	3.00	12.00		Rosengren (2014)
	Number of buckets used for window washing	buckets/event	PO	0.50		1.00		Engineering estimate
	Volume of bucket	L/bucket	LN	6.00	2.00	1.00	10.00	Rosenberg (2007)
	Percentage occurrence of eyecare	%	BN	0.61				CBS (2013)
	Frequency of eyecare	events/c/d	PO	2.25			3.00	Engineering estimate
	Volume of eyecare	L/event	LN	0.75	0.25			Engineering estimate
	Volume of other emergencies	L/event	UN			1.00	50.00	Engineering estimate
	Frequency of other emergencies	events/c/year	UN			1.00	52.00	Engineering estimate
Irrigation	No outdoor use allowed							
Car Wash	Car washes were assumed to be waterless or not allowed, else public transport was taken							
Leaks	Leaks are excluded – to be calculated separately							

Swimming Pool	No outdoor use, including swimming pools, was allowed

Table C 4: Parameters modified from the REAL consumption lifestyle level for ABC lifestyle level

	Parameter	Unit	Dist.[1]	μ	σ	Min	Max	Reference
Toilet	Flush frequency	flushes/c/d	PO	2.00		1.00	3.00	The City of Cape Town (2018)
	Volume of 9 L single	Not allowed						
	Penetration rate of toilet type	%	DC^L					Blokker et al. (2010); Gleick et al. (2003)
Shower	Penetration rate of low flow showerheads	%	BN	1.00				The City of Cape Town (2018)
	Normal shower head flow rate	Not allowed						
	Low flow shower head flow rate	L/s	UN			0.10	0.15	Rosenberg (2007); Blokker et al. (2010)
	Shower duration	s	LN	180.00	45.00	120.00	300.00	Roberts (2005); Blokker et al. (2010); DeOreo et al. (2011); Hand (2005)
	Shower frequency	events/c/d	DC^M					LCM Model Survey
Bath	Percentage occurrence for relaxation	Not allowed						
	Frequency of bath for relaxation	Not allowed						
	Volume of bath	L/bath	UN			20.00	40.00	The City of Cape Town (2018); Jacobs (2004)
	Bath frequency	events/c/d	DC^M					LCM Model Survey
Brushing Teeth	Volume for teeth brushing	L/event	TR	0.40		0.20	0.60	Chestnutt (1998); Matos (2013)
Hand Washing	Hand washing frequency reduced by 30%							
Shaving	Not allowed							

	Parameter	Unit	Dist.[1]	μ	σ	Min	Max	Reference
	Volume of other emergencies	L/event	UN			1.00	10.00	
Miscellaneous Activities	Volume of Cleaning Fridge	Not allowed						
	Frequency of fridge clean	Not allowed						
	Frequency of empty dishwasher run	Not allowed						
	Frequency of empty washing machine run	Not allowed						
	Frequency of window washing	Not allowed						
	Number of buckets used for window washing	Not allowed						
	Volume of bucket	Not allowed						

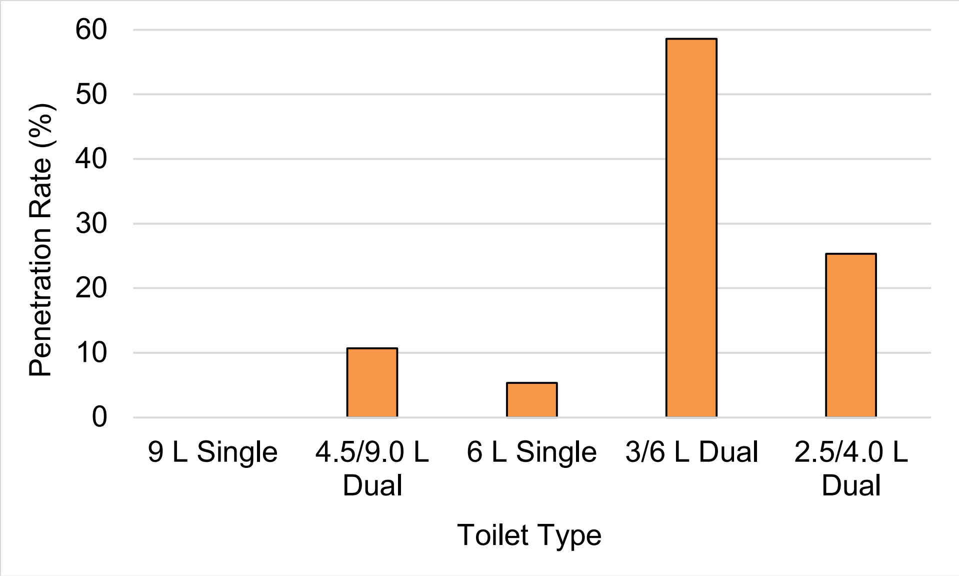

Figure C 12: L - Histogram of penetration rate of toilet type for ABC

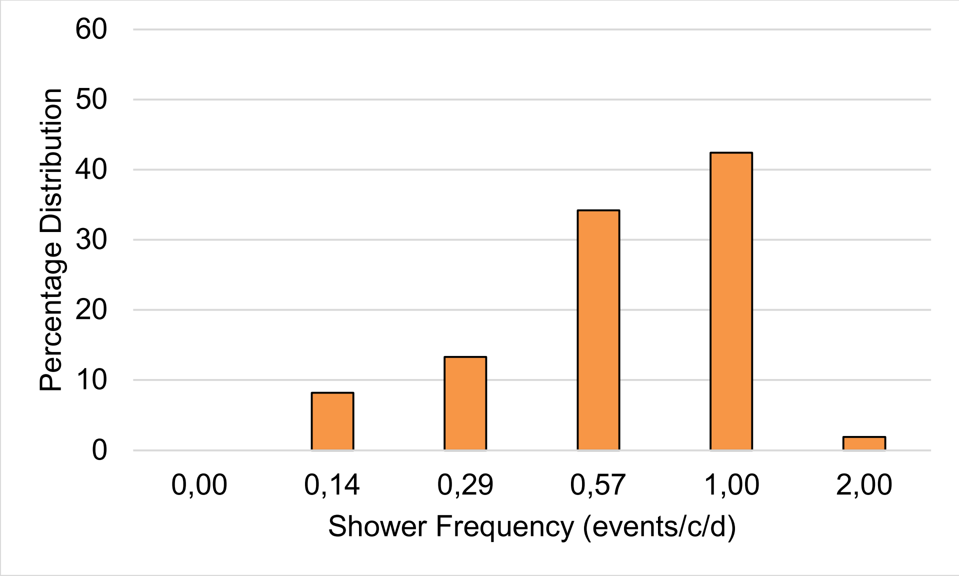

Figure C 13: M - Distribution of shower frequency for ABC lifestyle