Quantification of Regional Scale Water Quantity and Quality Implications of Rainwater Tanks in South East Queensland

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO’s Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South-East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South-East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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We would also like to thank Lavanya Susarla of the Moreton Bay City Council, for providing access to the final draft of the Moreton Bay Total Water Cycle Management plan report.

This study could not be undertaken without the data on tank sizes, roof areas and household end use water consumption. Such data was collected in parallel while undertaking this study, which posed a considerable challenge for completing the analysis required for the study. We used a staged approach in which the analysis was undertaken as soon as the data was processed.

We sincerely thank the following colleagues, for providing access to the required data as they became available, rather than keeping us on hold until the data was published:

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region’s emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO’s Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO’s Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

C. Davis

Chris Davis
Chair, Urban Water Security Research Alliance

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The South East Queensland (SEQ) Regional Plan 2009-2031 requires water management in SEQ to comply with the principles of Total Water Cycle Management (TWCM). This is to ensure that the land use and infrastructure planning in SEQ is environmentally sustainable, and that reliable water supplies are available to cater for forecast population growth. In SEQ, TWCM is to be achieved through the development of sub-regional and local government TWCM plans. Sub-regional TWCM plans give a greater emphasis to water supply values at the regional scale, whereas local government TWCM plans place a greater emphasis on values relating to protecting the health of the environment. Use of rainwater is generally considered as an integral part of both sub-regional and local government TWCM plans. This is because: (a) the Queensland Development Code MP 4.2 included a mandatory requirement for all domestic dwellings built after 1 January 2007 to meet a water savings target of 70 kilolitres per household per year (kL/hh/yr) in SEQ, with the installation of domestic rainwater tanks listed as one of the preferred options to meet that target (Queensland Development Code, 2008)[1]; and (b) capturing rainwater from urban catchments has the potential to improve both supply security and the health of waterways in the SEQ region. Consequently, understanding the potential contribution of rainwater tanks to securing the supply at the SEQ regional scale and improving catchment water quality became an essential need in SEQ. The study described in this report was designed to address this need.

The objectives of the study were to:

- Develop a methodology to robustly quantify the contribution of rainwater tanks to SEQ's grid water supply and improvements to catchment water quality; and
- Apply the methodology to the Moreton Bay local government area, as a demonstration on how the methodology can be used to inform the development of TWCM plans at the local government area scale.

The methodology adopted was 'stochastic simulation', a generic method applicable to any field of study. It allowed an iterative evaluation of a deterministic model consisting of a set of processes, using a set of random numbers drawn from probability distributions assigned to each input variable of the processes being modelled. In this study, we applied the stochastic simulation method to the factors that affect storage (or yield) and nutrient and sediment mixing behaviour of rainwater tanks.

The rainwater tank model of Mitchell *et al*. (2008) was used for this study. The input variables of the rainwater tank model were tank size, effective roof area, losses from the roof and household water use. Stochastic characteristics for tank size, effective roof area and losses from the roof were defined in a form of probability distributions derived from the observed data of such variables sourced from Biermann *et al*. (2012) and the Queensland Water Commission. The rainfall and evaporation data for the relevant areas were obtained from the Bureau of Meteorology. Stochastic characteristics for the demand placed upon the tank were defined in the form of a set of probable time-series, generated using a probability based demand prediction method based on Duncan and Mitchell (2008). The probabilistic demand model required water consumption data of household end uses and the maximum daily temperature to predict the water demand of each household end use over the period of simulation. The household demand data were sourced from Beal and Stewart (2011) and the maximum daily temperature data for the relevant areas were obtained from the Bureau of Meteorology.

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[1] Buildings in Queensland no longer have to meet compulsory water savings targets, following the repeal of laws mandating the installation of water supply systems on 1 February 2013. Previously, all new homes and commercial and industrial buildings in Queensland were required to install rainwater tanks or other water supply systems such as grey water treatment plants. Provisions have been made for local governments to opt-in to water savings requirements in recognition of Queensland's varying climatic conditions and regional circumstances. Builders in these local government areas will still need to comply with water savings requirements.

Water supply systems such as rainwater tanks and grey water treatment plants can still be installed voluntarily by homeowners and builders in all areas of the state. Builders who install a water saving system (either voluntarily or to meet local government requirements) must comply with the health and safety standards set out in the Queensland Development Code Part 4.2 – Rainwater tanks and other supplementary water supply systems (for residential – class 1, 2 and 10 - buildings) and Part 4.3 – Supplementary water sources – commercial buildings (for commercial and industrial - class 3-9 - buildings). (Source: Department of Housing and Public Works, 2013).

The study quantified the tank yield (i.e. the amount of SEQ grid water saved through the use of rainwater) and the tank overflow for five local government areas (LGAs) in the SEQ region: Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich. The required data was not available to quantify water quality parameters (i.e., total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS)) and loads associated with the overflow. Hence, we used literature-based data to examine the water quality implications. The simulation period of the study was 50-year period from 1 January 1962 to 31 December 2011.

The key findings of the study were:

1. The observed data on tank sizes exhibited a variation across and within the LGAs. The mean observed tank sizes for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich were 4.4, 5.54, 5.63, 5.61 and 6.67 kilolitres (kL), respectively. The coefficient of variation of the tank sizes was: 61%, 29%, 82%, 15% and 63% respectively for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich. *(It should be noted that throughout this report, the effective volume of a rainwater tank was referred as 'tank size'. The effective volume is the volume of water available between the outlet and overflow valves of the tank.)*
2. The observed data on roof area connected to the tank exhibited a variation across and within the LGAs. The mean observed roof area connected to the tank was: 116.6 m^2 for Brisbane, 102.07 m^2 for Moreton Bay and 97.61 m^2 for Gold Coast. The coefficients of variation of the connected roof areas were: 42% for Brisbane, 46% for Moreton Bay and 45% for Gold Coast. Roof areas were not available for Sunshine Coast and Ipswich, for which Moreton Bay data was assumed to be applicable.
3. The observed data on household end uses exhibited a variation across and within the LGAs as well. The observed totals of household water consumption (without leaks) were: 130 L/p/d (litres per person per day) in Brisbane, 157 L/p/d in Sunshine Coast, 150 L/p/d in Gold Coast and 109 L/p/d in Ipswich.
4. Using the stochastic simulation approach, we showed that, if the spatial variability exhibited in tank sizes, roof areas, water demand and water losses due to different types of roofs was ignored, errors could be introduced, for both water quantity and quality implications from a large number of rainwater tanks spread across an area. The errors introduced to tank yield varied from 10% overestimation in Gold Coast to 22% overestimation in Ipswich, with a mean error of 15% overestimation over the five LGAs considered in the study, compared to the tank yield obtained by considering the spatial variability of such variables. Similarly, the errors introduced to tank overflow varied from a 6% underestimation in Gold Coast to 20% underestimation in Ipswich, with a mean error of 11% underestimation over the five LGAs considered in the study, compared to the tank overflow obtained by considering the spatial variability of such variables. *(It should be noted that observed data was not available for water losses from different types of roofs. Hence literature-based data was used for roof losses.)*
5. A sensitivity analysis was conducted to understand the sensitivity of the spatial variability exhibited by each input variable of the rainwater tank simulation to the tank yield and overflow. Spatial variability of the demand placed on the rainwater tank was the most sensitive parameter to both tank yield and overflow. For example, the overestimation error associated with Brisbane's tank yield was 16%, which could be reduced to 6% by considering the spatial variability of demand alone. Considering the variability in roof areas alone could reduce the overestimation of tank yield to 11%; and considering the variability in tank sizes alone could reduce the overestimation of tank yield to 14%. For the accurate and robust prediction of water quantity and quality implications from a cluster of rainwater tanks, these results implied the need for predicting the household end use as accurately as possible and for considering the spatial and temporal variability of household water use.
6. The expected yield from domestic rainwater tanks varied across SEQ. The tank yields expected for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich were 42, 43, 48, 44 and 34 kL/hh/yr, respectively. These tank yield values represented the 50th percentile (or median) value of 10,000 tank yield values obtained through stochastic simulation of the tank storage over the 50-year period. The average tank yield found from our study was 42 kL/hh/yr (i.e. the

average of the five LGAs). *(It should be noted that observed data was not available to compare tank yields obtained through stochastic simulation.)*

7. The tank yields found in this study were in the same order of magnitude when compared with tank yield studies conducted in SEQ by Beal *et al*. (2012) (50 kL/hh/yr), Chong *et al*. (2011) (58 kL/hh/yr), Umapathi *et al*. (2012) (40 kL/hh/yr) and QWC (2011) (37 kL/hh/yr), which provided some validity to the yield estimates found through stochastic simulation.
8. Considerable variation could be expected for the yield of individual tanks in a cluster of tanks spread across an area, which could be a suburb, a LGA or a region. The expected ranges for tank yields obtained through stochastic simulation were: 4-117 kL/hh/yr for Brisbane, 4-125 kL/hh/yr for Moreton Bay, 15-154 kL/hh/yr for Sunshine Coast, 5-107 kL/hh/yr for Gold Coast to 0-104 kL/hh/yr for Ipswich. The average range over the five LGAs was 6-121 kL/hh/yr.
9. Given the variation in rainfall across SEQ region, it was not appropriate to use the average value of tank yield as a generalised value for the SEQ region. However, if a value was needed for the tank yield in SEQ, particularly for urban water planning studies, it would be reasonable to use the average value of all the yield figures reported in the study, i.e. 42 kL/hh/yr or 44 L/p/d. This was because the LGAs considered for the study were located in the north, south, east and west of the SEQ region, and in terms of water use, these LGAs showed a representative variation across the region (Beal and Stewart, 2011).
10. The expected overflow from domestic rainwater tanks varied across SEQ. For Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich, the expected values for overflows were 44, 49, 68, 57 and 27 kL/hh/yr, respectively. The average over the five LGAs was 49 kL/hh/yr.
11. If rainwater was used for toilet use, clothes washing and garden use, rainwater could meet about 72% of the demand placed on the tank (i.e., volumetric reliability was 72%). This was the average of 68%, 69%, 74%, 80% and 70% volumetric reliability found for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich, respectively.
12. The water quality analysis based on the data on TP, TN and TSS sourced from the literature indicated that ignoring the spatial variability present in tank sizes, roof areas, losses from the roof, inflow concentrations of TP, TN and TSS into the tank and the demand placed on the tank, could introduce errors to the quality of overflow water. The magnitudes of the error for the loads associated with the overflow were: 17% underestimation for TSS, 22% underestimation for TP and 15% underestimation for TN, compared to a case that considered the spatial variability of the above mentioned factors. Unlike the tank yield and tank overflow results, the results related to TP, TN and TSS should be used cautiously because they were based on data sourced from the literature.
13. As expected, rainfall showed a positive correlation with both tank yield and tank overflow, i.e. the higher the rainfall, the higher the tank yield and overflow.
14. When using the stochastic simulation approach, care should be taken on the time-step of simulation and the number of iterations of the stochastic simulation. Hourly time-step of simulation would be preferable to a daily time-step. However, for yield studies, comparable results to hourly time-step simulation could be obtained by undertaking behavioural simulation of rainwater tank storage on a daily basis. It was found that the tank yield obtained with daily simulation was about 2% more than the yield obtained with hourly simulation. Hence, we used a daily time-step for this study. The number of iterations required for the stochastic simulation could vary depending on the probability distributions used for input variables. Through trialling of different numbers of iterations, 10,000 iterations were found to be sufficient to ensure adequate sampling from the probability distributions of the input variables.

The tank yields and tank overflows found from the study can be used to inform the development of TWCM plans in Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich local government areas, and the strategic water supply planning in SEQ, in terms of the amount of grid water saved by the use of rainwater tanks and the amount of overflow expected to occur from the rainwater tanks. For the areas in SEQ not included in the present study, the error values provided for yield and overflow might be used to correct the yield and overflow values obtained with deterministic simulation of rainwater tanks. Deterministic simulation is easy to conduct because it simply uses the average values for tank sizes, connected roof areas, roof losses and the water demand. However, it is important to note that the error values reported in this study are not generic and that they vary depending on the climate (rainfall), tank yield characteristics and the water use characteristics. For water quality implications, the error values given in the report should be used cautiously, because they are based on data sourced from the literature.

Organisations interested in applying the stochastic simulation methodology for rainwater tanks may use the rainwater tank model and the stochastic demand generator model used in this study. The stochastic demand generator model is available through eWater CRC's Urban Developer model (http://www.ewater.com.au/). The rainwater tank model has also been developed by eWater CRC and a copy of this model may be obtained by contacting the eWater CRC (http://www.ewater.com.au/).

Results presented in the report can be enhanced by improving the limitations presented in both the rainwater tank model and the stochastic demand generator model, and by using an adequate and representative data sample to derive probabilities. In regard to the models, the key limitation is not being able to assign any type of probability distribution (either theoretical or the observed) to input variables of both models. In regard to the data, the key limitation is the unavailability of data that can adequately represent the area being considered. This study has used the most up to date data, but the sample sizes are less than 100 data points in most cases, which is not adequate for an area of about 22,000 km^2.

1. INTRODUCTION

1.1. The Need

Recently, water security has become a high priority issue in most major cities in Australia. This is due to prolonged drought conditions occurred across the continent. Use of alternative water sources such as rainwater, stormwater and recycled wastewater has been promoted to reduce the pressure placed on conventional sources such as surface water and groundwater. South East Queensland (SEQ), which is one of the fastest growing urban regions in Australia, covering about 22,420 km^2, experienced one of its most severe droughts on record during 2001 – 2009. As an attempt to improve water security in SEQ, the Queensland Development Code MP 4.2 (QDC MP 4.2) included a mandatory requirement for all domestic dwellings built after 1 January 2007 to meet a 70 kilolitre per household per year (kL/hh/yr) water savings target in SEQ[2]. One of the preferred options to meet that target was the installation of a 5 kilolitre (kL) rainwater tank, connected to 100 m^2 roof area (or at least half the roof area, whichever is the lesser) and connected to the toilet(s), cold water tap for the clothes washing machine and an external tap (Queensland Development Code, 2008).

The use of alternative water sources, including rainwater tanks, was also promoted by the South East Queensland Regional Plan 2009-2031 (Queensland Government, 2009), which required water management in SEQ to comply with the principles of Total Water Cycle Management (TWCM). This was to ensure that the land use and infrastructure planning in the SEQ was environmentally sustainable, and that reliable water supplies were available to cater for forecast population growth. In SEQ, TWCM was to be achieved through the development of sub-regional and local government TWCM plans. Sub-regional TWCM plans gave a greater emphasis to water supply values at the regional scale whereas local government TWCM plans placed a greater emphasis on values relating to protecting the health of the environment. The common challenge at all scales of TWCM planning was to be able to rigorously and robustly evaluate alternative urban water servicing options, in order to defend decisions as being "prudent" in terms of not only direct cost of supply but also in terms of costs and benefits to the environment, which may or may not be directly translatable to monetary values. Hence, there was a need for each impact (e.g. contribution to SEQ's grid water supply and reductions in nutrient loads to waterways) to be presented in an explicit and comparable form so that it was clear to decision-makers what the relative impacts of different water management options was and what trade-offs needed to be made when choosing a particular water management option.

In the TWCM context, use of rainwater was considered as an alternative water management option with the potential to improve both supply security and the health of waterways in the SEQ region. Hence, capture and use of rainwater was considered as an integral part of both sub-regional and local government TWCM plans. Consequently, understanding the potential contribution of rainwater tanks to securing the supply at the SEQ regional scale and improving catchment water quality became an essential need, particularly for the organisations involved in developing the TWCM plans. Such organisations included the regional councils, the Queensland Water Commission (QWC) and the Queensland Department of Environment and Resource Management (DERM). Regional councils were responsible for the development of TWCM plans for the local government areas, whereas the QWC was responsible for the development of TWCM plans for the major growth areas identified in the Queensland Regional Plan 2009-2031. DERM was responsible for ensuring the local government area TWCM plans met Environmental Protection (Water) Policy 2009 (Queensland Government, 2009) requirements, which prescribed that all Local Government Areas (LGAs) that contained over a certain population must develop and implement a TWCM Plan specific to its local government area.

A common question asked by the organisations responsible for the development of TWCM plans in the SEQ, as well the authorities responsible water management in urban areas, in regard to rainwater tanks was whether the potential implications on SEQ's grid water supply and the health of waterways in the SEQ could be determined by linearly up-scaling both supply and overflow implications of an individual household tank. Furthermore, there was a keen interest to understand the underlying reasons

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[2] See Footnote 1 for changes to this requirement from 1 February 2013.

and the magnitude of the error introduced if linear up-scaling was not appropriate. The study described in this report was designed to address this need.

1.2. Research Objective

The objectives of the study are to:

- Develop a methodology to robustly quantify the contribution of rainwater tanks to SEQ's grid water supply and improving catchment water quality; and
- Apply the methodology to the Moreton Bay local government area to quantify potable water savings and reductions in nutrient and sediment discharges to Moreton Bay, as a demonstration on how the methodology can be used to inform the development of TWCM plans at the local government area scale.

1.3. Report Structure

Chapter 1 describes the need and the research objectives of the study.

Chapter 2 describes the methodology.

Chapter 3 describes the application of the methodology to SEQ and the results of the application.

Chapter 4 provides a summary of results and discussion on results.

Chapter 5 describes the conclusions of the study and briefly, outlines further work that could be undertaken in the future for enhancing the application described in Chapter 3.

2. METHODOLOGY

2.1. Literature Review

A common approach used by the practitioners to quantify both quantity and quality implications (e.g., potable water savings and overflow from tanks on stormwater flows and associated nutrient and sediment loads) from a cluster of rainwater tanks (i.e., a large number of domestic rainwater tanks spread across a large area, e.g. a large development, a suburb or a local government area) is, linear extrapolation of both quantity and quality implications obtained from a single tank with average tank and water demand characteristics. This approach assumes that both quantity and quality implications of individual domestic rainwater tanks in a given area are the same for all the tanks and, that the factors affecting supply and overflow from the tank have linear relationships with both quantity and quality implications.

However, several studies have shown that the amount of water supplied and the amount of over flow from rainwater tanks varies with such factors as prevailing climate, tank volume, area of the roof connected to the tank and household water use (Fewkes and Butler, 2000; Fewkes and Warm, 2000; Coombes and Barry, 2007; Mitchell, 2007; Ghisi, 2010; Basinger *et al.*, 2010; Khastagir and Jayasuriya, 2010; Palla *et al.*, 2011 and Neumann *et al.*, 2011). Through field measurement of physical characteristics of rainwater tanks in SEQ, Biermann *et al.* (2012) have showed that tanks sizes and connected roof areas vary spatially despite the fact that there is a recommended tank size of 5 kL and a roof area connected to the tank of 100 m^2 specified by the Queensland Government (Queensland Development Code Mandatory Part (MP) 4.2, 2008). Several studies on household end use measurements have clearly shown that the volume of water use by individual end uses varies spatially, from house to house (Roberts, 2005; Willis *et al.*, 2009; Beal and Stewart, 2011). Therefore, it can be said that rainwater tank yield and tank overflow vary with such factors as tank sizes, connected roof area to the tank, the demand placed on the tank and the prevailing climate, and that these factors can vary both spatially and temporarily. Consequently, it is not realistic to consider that tank yield and tank overflow from individual tanks spread across an urban area, would remain the same.

Evidence for the spatial variability of supply from domestic rainwater tanks has been reported in Beal *et al.* (2012), Chong *et al.* (2011) and Umapathi *et al.* (2012). These studies have analysed water consumption data obtained from households with and without rainwater tanks to quantify supply from rainwater tanks. All three studies have been conducted in SEQ. Beal *et al.* (2012) analysed 2008 water consumption data to show that rainwater tank yield in the SEQ varied from 20 kL/hh/year to 95kL/hh/year with a mean of 50 kL/hh/year. Chong *et al.* (2011) analysed 2008 and 2009 consumption data to show that rainwater tank supply in the SEQ varied from 25 kL/hh/year to 89 kL/hh/year with a mean of 58 kL/hh/year. Umapathi *et al.* (2012) analysed 2010 consumption data and reported a mean rainwater tank supply in the SEQ during 2011 as 40 kL/hh/year. Similarly, the QWC conducted a study using 2011 Brisbane-based consumption data and showed a mean annual tank supply of 37 kL/hh/year (personal communication with Mark Askins, Queensland Water Commission, 2011). These studies clearly show that supply from rainwater tanks can vary spatially as well as temporarily.

Non-linearity of the factors affecting both tank supply and overflow (i.e. water use characteristics and tank characteristics) has been examined by several researchers (Mitchell, 2007; Neumann *et al.*, 2011; Maheepala *et al.,* 2011). They have clearly shown non-linear relationships with both tank supply and overflow with tank characteristics (Figure 1) and water use characteristics. Therefore, it is likely that an approach that uses linear up-scaling of the yield of a single tank with average characteristics to determine the supply from multiple rainwater tanks (i.e. ignoring of the non-linearity of the factors affecting both supply and overflow from a tank), can introduce errors.

Linear up-scaling or ‘spatial lumping’ effect of multiple domestic rainwater tanks on the collective yield from tanks has been examined in a number of studies (Mitchell *et al.*, 2008; Xu *et al.*, 2010; Maheepala *et al.*, 2011; Mashford *et al.*, 2011 and Coultas *et al.*, 2011). The spatial lumping effect of tanks on water quality implications of a cluster of domestic rainwater tanks have been studied by Neumann *et al.* (2011). All these studies have considered the spatial variability of the above-mentioned factors. They have shown that the use of average values for rainwater tank characteristics as well as for household water demand can result in an overestimation of the supply from a system with multiple tanks. The overestimations of tank supply reported in these studies, are in the order of 14% for Melbourne-based data (Mitchell *et al.*, 2008; Xu *et al.*, 2010; Maheepala *et al.*, 2011), 18% for Canberra-based data (Maheepala *et al.*, 2011) and 14% for Brisbane-based data (Coultas *et al.*, 2011). An overestimation of tank supply means an underestimation of overflow from the tank. The lumping effect of rainwater tanks on tank overflows and nutrient and sediment loads has been examined by Neumann *et al.* (2011). They reported 37% under-estimation of overflow and 30% under-estimation of nutrient and sediment loads, corresponding to 14% over estimation of tank supply, for Melbourne-based data.

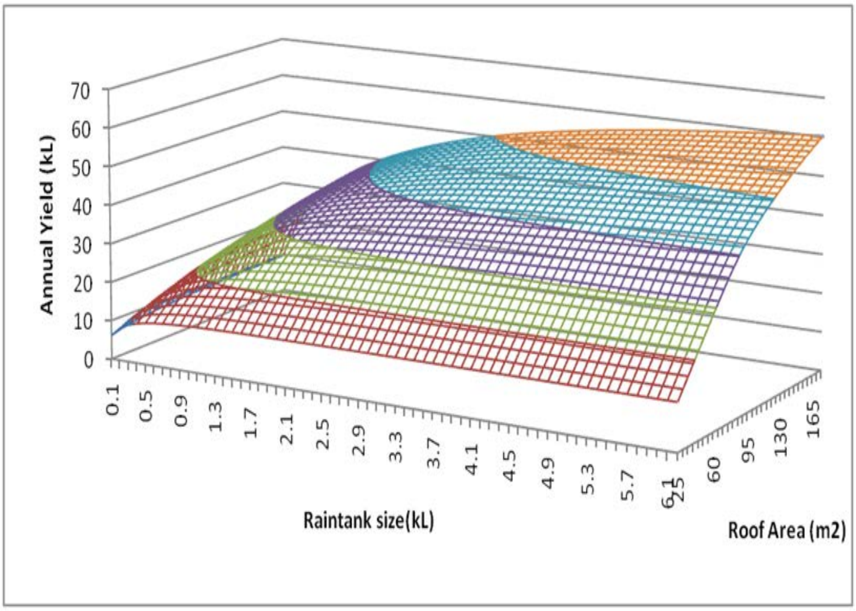


Figure 1. **Curved surface of the tank yield indicates a non-linear relationship between tank yield, tank sizes and the connected roof areas (source: Neumann *et al.,* 2011).**

These studies support the argument that supply and overflow from a cluster of rainwater tanks, cannot be quantified through linear up-scaling of the corresponding impacts, computed using a single tank of average characteristics. The recommended approach by several researchers (Mitchell *et al.*, 2008; Xu *et al.*, 2010; Maheepala *et al.*, 2011; Mashford *et al.*, 2011; Coultas *et al.*, 2011; Neumann *et al.*, 2011 and Maheepala *et al.*, 2012) is 'stochastic simulation' of rainwater tank behaviour, which is a method for iteratively evaluating a deterministic model, using sets of random numbers as inputs (Kroese *et al.*, 2011).

2.2. Methodology

This study used the stochastic simulation approach to quantify supply (i.e. yield), overflow and water quality implications from a set of multiple rainwater tanks (or a cluster of tanks) in SEQ. This study can be considered as an extension to the study reported in Coultas *et al.* (2011) in which they have examined potable water savings, overflow and water quality implications from a cluster of rainwater tanks in Brisbane using the stochastic simulation approach. This study extends the same methodology to a number of local government areas in SEQ and enhances Coultas *et al.* (2011)'s Brisbane results further by using an updated set of: (a) household end use data sourced from Beal and Stewart (2011); and (b) tank and roof area data sourced from *Biermann et al.* (2012).

The stochastic simulation approach allows considering all probable values of the input variables of the process to be simulated. Probability distributions are generally used to specify probable values for each input variable. In contrast, the commonly used deterministic simulation approach allows the use of a single value for each input variable of the process to be simulated, which in most cases was an average value for the each input variable. The accuracy of the outputs of the stochastic simulation approach depends on how well the probability distributions of input variables represent the observed data. Hence, it is important to use adequate samples of observed data to derive probability distributions. In general, a sample containing more observed data is better than a sample with a small amount of observed data. The output of stochastic simulation represents a probable or likely set of values for the output variables, which can be represented as probability distributions, to place confidence levels on the selected value of output variables.

Application of the stochastic simulation method to rainwater tanks, to achieve the objectives of the study as described in Chapter 1, involved simulation of both storage and contaminant mixing behaviour of a rainwater tank by considering stochastic characteristics for the factors that affected the storage and nutrient and sediment mixing behaviour of the tank. The factors included tank sizes, effective roof area, losses from the tank and roof and household water use. Stochastic characteristics for the input parameters should be defined either in a form of probability distributions or in a form of a large number of probable values generated using probability based methods that utilise probable values of the observed data of the input parameters.

To simulate the processes of storage and nutrient and sediment mixing behaviour in a rainwater tank, a model was required. Details of the model used are described below.

2.2.1. Stochastic Simulation of Rainwater Tank Storage Behaviour

The stochastic simulation required a rainwater tank model with ability to specify probability distributions for the input parameters. The tank model described in Mitchell *et al.* (2008) had such characteristics and hence it was used for this study. A schematic diagram of this model is shown in Figure 2.

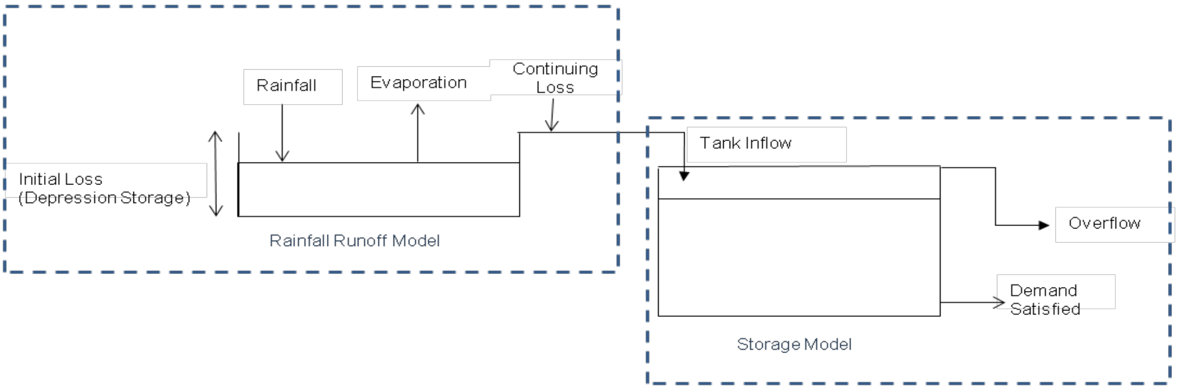


Figure 2. Schematic representation of the rainwater tank model (source: Neumann 2011, adapted from Mitchell *et al.*, 2008).

The Mitchell *et al.* (2008)'s rainwater tank (RWT) model was a water balance model, capable of simulating the processes involved in translating rainfall into roof runoff, and the tank storage by considering the demand drawn from the tank. It consisted of two modules: a rainfall-runoff module, which computed the amount of roof runoff into the tank, and a storage module, which computed the amount of water stored in the tank, using 'yield-after-spill' operating rule. The yield-after-spill operating rule allows the tank to supply water to satisfy the demand placed on the tank, after allowing water to spill from the tank if the inflow to the tank in a particular simulation time-step is greater than amount of water that can be held in the tank in that particular time-step. The yield-after-spill rule provides an accurate estimate for yield calculation compared to the approach that allows supply from the tank to occur before the spillage, yield-before-spill rule (Fewkes and Butler, 2000; Mitchell, 2007).

The rainwater tank model allowed each tank parameter (i.e. tank size, connected roof area and losses from the roof) to be specified either as a continuous probability distribution with a minimum and a maximum value, or as an average value. The losses should be specified as an initial loss and a continuing loss. Both losses can be either specified as probability distributions or average values. A limitation present in Mitchell *et al.* (2008) was that it allowed the use of only normal distribution, for the input variable. This limitation must be addressed in future studies.

The input data required for the rainwater tank model included rainfall and potential evaporation over the simulation period, connected roof area, initial and continuing losses from the roof, tank size (i.e. the effective volume of the tank) and the demand. The connected roof area, initial and continuing losses from the roof and tank size can be specified either as an average value or as a probability distribution function. The demand can be specified as a time series containing either an average value or a set of probable values, to account for the temporal variability of the water use over the time period of simulation. The use of probability distributions to connected roof area, tank size and roof losses meant that tanks were not considered as having a temporal variability over the simulation period.

To specify the demand placed on the tank as a probable set of time series, a method was needed to predict the demand stochastically. The method used in this study is described in Section 2.2.3.

2.2.2. Stochastic Simulation of Nutrient and Sediment Mixing

As mentioned above, the rainwater tank of Mitchell *et al.* (2008) was only a water balance model. Hence it was modified as part the study to include nutrient and sediment mixing capability. Modifications involved implementation of a first order kinetic decay model in the rainwater tank model, based on the “Continuous Stirred Tank Reactor” (CSTR) concept, i.e. the k-C model (eWater CRC, 2005).

The implementation of the k-C model in the rainwater tank model was tested by simulating a 5 kL tank attached to a 100 m^2 roof without losses. The simulation was run for a period of 20 years using standard k-C parameters for Total Suspended Solids (TSS) in the MUSIC model (eWater CRC, 2005). Two scenarios were considered, one with a constant inflow concentration of 158 mg/l and the second using MUSIC standard TSS storm flow parameters (mean 158 mg/l, standard deviation 47 mg/l). The first scenario tested the rainwater tank model performance with identical concentrations of TSS and inflows as the MUSIC model. In the second test, probable concentrations were generated from the normal distribution. The scenarios were compared in terms of long term performance, as the concentrations for each day were likely to be different since they were generated independently.

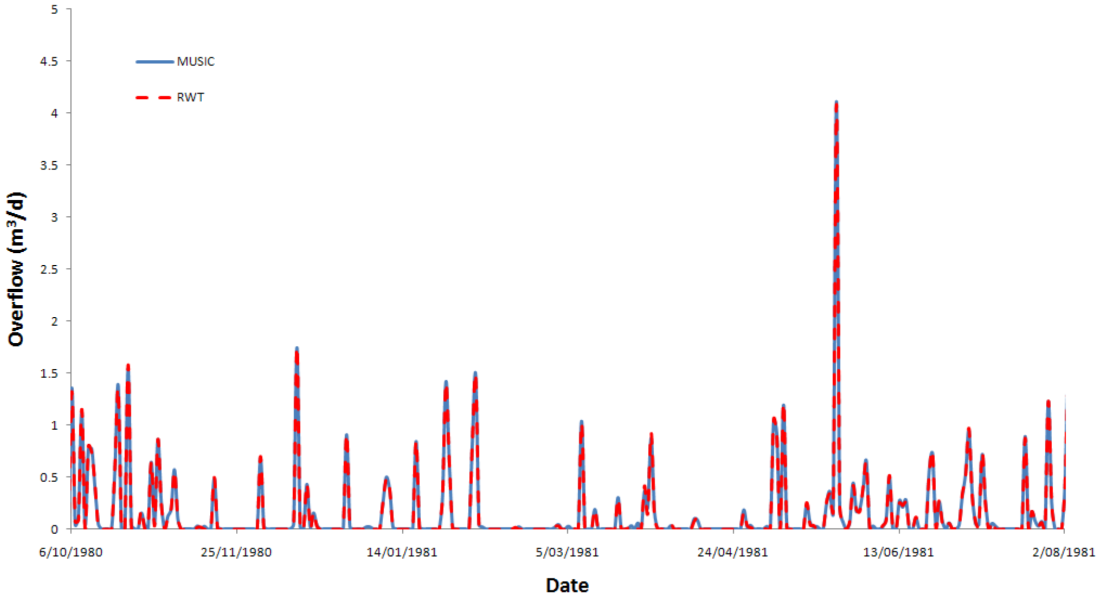


Figure 3. **Comparison of outflow rate MUSIC and the modified RWT models.**

Table 1. **Average inflow, outflow, concentrations and load for the MUSIC and rainwater tank comparisons.**

Parameter	Average Inflow $(m^{(3)}/y)$	Inflow Concentration (mg/l)	Average Inflow Load (kg/y)	Average Overflow $(m^{(3)}/y)$	Average Outflow Load (kg/y)
MUSIC	42.56	158	6.72	42.56	0.89
		Stochastic	8.77		1.02
Rainwater tank	42.56	158	6.72	42.56	0.92
		Stochastic	8.92		1.04

Figure 3 shows a comparison between the overflow and constituent concentration of a rainwater tank as simulated by the MUSIC model and the modified RWT model. The overflow volume calculated by both models was very similar, as were the outflow concentrations for most of the simulation. The instances where the concentration results did differ were in time-steps where MUSIC reported no outflow and hence zero concentration but the rainwater tank reported a small outflow and hence a value similar to the previous time-step. In these instances, the outflow volume and hence associated loads were very small and did not affect the overall performance (Table 1). Both models had the same average inflow and overflow rates and for identical overflow concentrations, the outflow load calculated by the RWT model was 3.5% higher than the MUSIC model. For the stochastic inflow concentration case, the RWT model generated an inflow load that was 2% higher than the MUSIC, model with a corresponding 2% higher outflow load. These results indicated that the performance of both models were comparable.

2.2.2.1. Input parameter values for TSS, TP and TN

The First Order Kinetic process can be expressed algebraically as:

$$(C_{out} - C^{*}) / (C_{in} - C^{*}) = e^{-k/q}$$

Where, C^{*} is the background concentration; C_{in} is the input concentration; C_{out} is the output concentration; k is the rate constant, and q is the hydraulic loading (flow rate per surface area) of the treatment measure.

Table 2. **Rainwater Tank simulation input parameters for TSS, TP and TN.**

	TSS	TP	TN
k (m/yr)	400	300	40
C^{*} (mg/l)[1]	12	0.13	1.4
CSTRs to represent rainwater tank	2	2	2
Concentration In mean (mg/l)	3.39	0.03	0.3
(log mg/l)	0.53	-1.54	-0.52
Concentration In standard deviation (mg/l)	1.74	2.40	2.45
(log mg/l)	0.24	0.38	0.39

Note 1: C*values for TSS and k values for TP and TN are based on ponds, which were calibrated using a Melbourne-based data. C^{*} values for TN and TP were calibrated using Brisbane-based data.

To apply the methodology to SEQ, the appropriate values of for k, C^{*} and CSTR input parameters must be used for Total Nitrogen (TN), Total Phosphorus (TP) and TSS. We used default values given in the MUSIC model by eWater CRC. C_{in} values were taken from Brisbane City Council (2005). The following studies were used to calibrate MUSIC Treatment type values to observed data:

- Vegetated swale in Brisbane (Pinjarra Hills Estate) (Brisbane City Council, 2005)
- Stormwater pond / lake in Melbourne (Blackburn Lake) (RossRakesh *et al*, 1999)

The adopted values are shown in Table 2.

2.2.3. Stochastic Simulation of Household Water Demand

The demand time series required to simulate the storage behaviour of the rainwater tank, was generated (or predicted) using the stochastic demand generator (SDG) model described in Duncan and Mitchell (2008), which quantified the water demand of each household end use through a two stage process. The first stage defined the probability of an end use starting in a given time-step using diurnal data. The second stage quantified the volume of water use by that end use, during the given time-step. The household end uses included in the SDG model were: toilet use, tap use, showers, baths, dishwashers, clothes washers and garden irrigation. All end use demands were generated at one minute intervals, which were then aggregated to any higher order time-step.

Duncan and Mitchell (2008)'s stochastic demand model was slightly modified to suit the SEQ application. Modifications were:

- Changing fixed volumes (i.e. no distribution, same for every household) of water used for toilet frequency, clothes washer volume, dishwasher volume, tap volume, shower flow rate and irrigation flow rate to user-defined probability distribution. The probability distribution can be either obtained by fitting the observed data to normal or log-normal theoretical probability distributions or the cumulative probability distribution of the observed data (called 'observed PDF' approach). This modification allowed accounting for the spatial variability exhibited in the observed data; and
- Changing the modelling method of dishwasher and clothes washer uses (described below).

The modelling method of each household end use is described below.

2.2.3.1. Toilet Flushing

The full and half flush volumes for a given demand sequence (i.e. one household) were drawn from a user-defined normal distribution at the start of a run, then held at these values for the remainder of the generation run. This simulated the behaviour of a household with toilets that remained the same for relatively long periods. The probability of a toilet flush in a single one minute time-step was calculated from the typical number of flushes per day. Half flushes and full flushes are calculated separately and combined later. The probability calculations in each minute were as follows:

$\boldsymbol{P}_{\text{half flush}}$ = Occupants × Half flushes per person per day × Diurnal factor / Minutes per day

$\boldsymbol{P}_{\text{full flush}}$ = Occupants × Full flushes per person per day × Diurnal factor / Minutes per day

Toilet frequency and volume were sampled from the probability distributions derived from the observed values of frequency and volume of the toilet use.

2.2.3.2. Taps and Hand Basins

The probability of a minor tap usage occurring in any minute was calculated from the observed frequency of use. The probability calculation was as follows:

$\boldsymbol{P}_{\text{tap use}}$ = **f**(Occupants) × Diurnal factor / Minutes per day

Where, **f**(Occupants) represented uses per day as a linear function of the number of occupants.

For Brisbane, the observed tap use frequency is 58.70 events per day per household (with an average occupancy of 2.6 people). The following relationship was used for the frequency of tap use:

Number of tap uses per day = 22.58 X Occupants

The tap volume was sampled from a probability distribution derived from observed tap volume data.

2.2.3.3. Shower

The probability of a shower starting in a time-step was calculated from the typical number of showers per day. The probability calculation was:

$\boldsymbol{P}_{\text{shower start}}$ = Occupants × Showers per person per day × Diurnal factor / Minutes per day

A shower event generally occupied more than a single one minute time-step. Hence conditional probability approach was used to define the probability of a shower event occurring in a given time-step. Once a shower event occurred, the probability of extending it to the second time-step was considered as larger than the probability of extending it to the third time-step. This process was assumed to be continued for a number of minutes. The probabilities for each minute may be calculated from a histogram of observed shower durations, or may be found by trial and error calibration. For example, for Brisbane, the observed average shower duration was 5.72 minutes. The conditional probabilities found by calibration were:

$\boldsymbol{P}_{\text{2given1}} = 0.98$, $\boldsymbol{P}_{\text{3given2}} = 0.98$, $\boldsymbol{P}_{\text{4given3}} = 0.95$, $\boldsymbol{P}_{\text{5given4}} = 0.72$, $\boldsymbol{P}_{\text{6given5}} = 0.61$, $\boldsymbol{P}_{\text{7given6}} = 0.31$, $\boldsymbol{P}_{\text{8given7}} = 0.16$, $\boldsymbol{P}_{\text{9given8}} = 0.08$, $\boldsymbol{P}_{\text{10given9}} = 0.05$, $\boldsymbol{P}_{\text{11given10}} = 0.02$

The shower flow rate was sampled from a probability distribution constructed from the observed data.

2.2.3.4. Bath

Baths were assumed to be run at the user defined filling rate until the specified volume was reached. The probability of a bath starting in a given time-step was:

$\boldsymbol{P}_{\text{bath start}}$ = Occupants × Baths per person per day × Diurnal factor / Minutes per day

The original SDG model assumed fixed values for volume and flow rate. We used the same approach.

2.2.3.5. Dishwashers

The probability of the event occurring was calculated as follows:

$\boldsymbol{P}_{\text{dishwasher}} = F_{\text{frequency}}$ × Diurnal factor / Minutes per day

Where $F_{\text{frequency}}$ was loads per day, found through sampling from observed dishwasher frequencies.

It should be noted that in the original model of Duncan and Mitchell (2008), $\boldsymbol{P}_{\text{dishwasher}}$ was calculated by considering the occupancy rate, as follows:

$\boldsymbol{P}_{\text{dishwasher}} = \mathbf{f}(\text{Occupants})$ × Diurnal factor / Minutes per day

Where, $\mathbf{f}$(Occupants) was loads per day as a linear function of the number of occupants.

In our approach, dishwasher use was not calculated for individual occupancy rates. This was because the available data sample did not differentiate dishwasher volumes and frequencies by the occupancy rates. Therefore, it was not possible to develop a relationship for loads per day as a function of the number of occupants. This problem was overcome by sampling the frequency of dishwasher use from the observed data of the whole sample, which contained households of varying occupancy rates.

Similar to dishwasher frequencies, the dishwasher volume per each event was drawn through random sampling from the observed data.

2.2.3.6. Clothes washers

The method used for clothes washer was similar to the method used for dishwasher, i.e. the probability of the event occurring for clothes washer was calculated as follows:

$\boldsymbol{P}_{\text{clothes washer}} = F_{\text{frequency}}$ × Diurnal factor / Minutes per day

Where $F_{\text{frequency}}$ was loads per day, which was found through sampling from the observed clothes washer frequencies.

In the original model of Duncan and Mitchell (2008), $\boldsymbol{P}_{\text{clothes washer}}$ was calculated by considering the occupancy rate, as follows:

$\boldsymbol{P}_{\text{clothes washer}} = \mathbf{f}(\text{Occupants}) \times \text{Diurnal factor} / \text{Minutes per day}$

Where, **f**(Occupants) was loads per day as a linear function of the number of occupants.

Similar to clothes washer frequencies, the clothes washer volume per each event was drawn through random sampling from the observed data.

2.2.3.7. Garden/Irrigation

Garden water use generally influenced by climatic factors. To understand the influence of climatic factors on garden water use, the total daily water use in Brisbane was plotted against the daily rainfall, daily maximum temperature and daily evaporation in Brisbane, for 1 January 2000 to 31 December 2004 (Figure 4, Figure 5 and Figure 6).

The scatter data plots of daily water use and daily maximum temperature showed a trend, whereas daily water use and daily rainfall did not show any trend (Figure 7), which implied that the total water use in Brisbane was correlated better with maximum daily temperature (and also with daily evaporation, but generally evaporation and temperature were considered as closely correlated) than the daily rainfall. Therefore, it was considered that triggering of garden watering can be better related to the daily maximum temperature than the daily rainfall. It should be noted that the original SDG model used the same assumption, on the basis that Melbourne’s garden watering events were closely correlated with the daily maximum temperature.

The probability of a garden watering event starting in a given time-step was assumed to be correlated to the daily maximum temperature and calculated as follows:

$\boldsymbol{P}_{\text{garden}} = \mathbf{f}(\text{Max Temp}) \times \text{Diurnal factor} / \text{Minutes per day}$

Where, **f**(Max Temp) was irrigation periods per day as a linear function of temperature above a certain minimum value, determined either through calibration or by analysing daily water use and daily maximum temperature data.

Once a watering event started, there was a constant (and relatively high) probability of it continuing into the next one minute time-step. The flow rate was assumed to remain constant for the duration of the event.

The probability of a garden watering event starting in any time-step on a given day was considered as a simple threshold function of daily maximum temperature. The larger the temperature excess above the threshold on a given day, the higher the probability of watering starting in any time-step on that day.

For SEQ, we adopted a threshold of 18°C. This value was determined through calibration, to best-fit the observed data. Once a garden watering event started, a constant probability was assumed, for it to continue into the next time-step. A suitable value for the probability (i.e. 0.85) was obtained through the calibration. The key reason to assign values through calibration was the use of winter data set, which exhibited a low water consumption for irrigation and general outdoor purposes.

The volume of water use for garden watering was sampled from the probability distributions derived for mean flow rate and the duration of water use using the observed data. The flow rate was assumed to remain constant for the duration of the event.

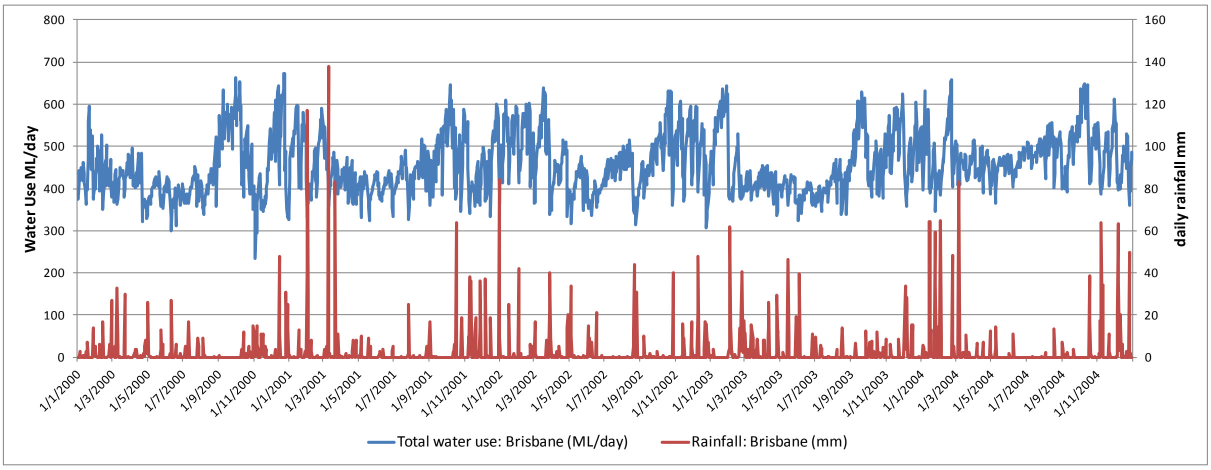


Figure 4. **Brisbane: Daily water use and daily rainfall.**

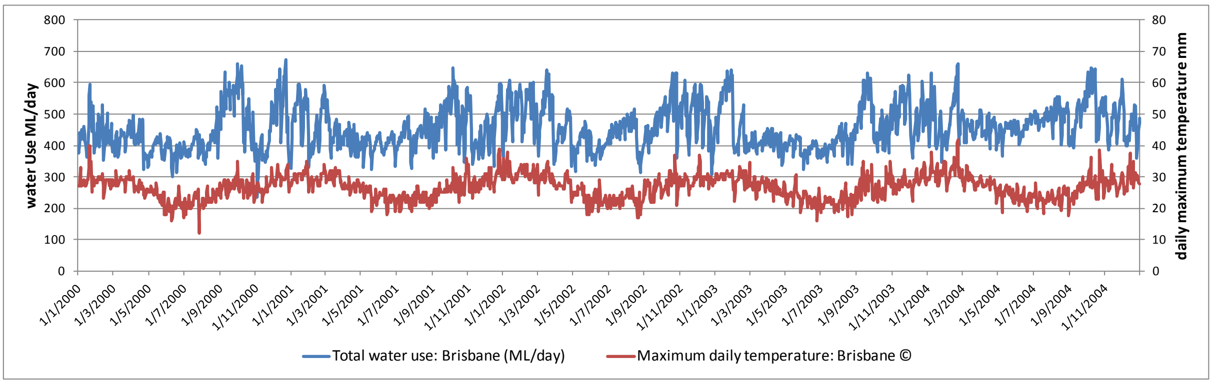


Figure 5. **Brisbane: Daily water use and daily maximum temperature.**

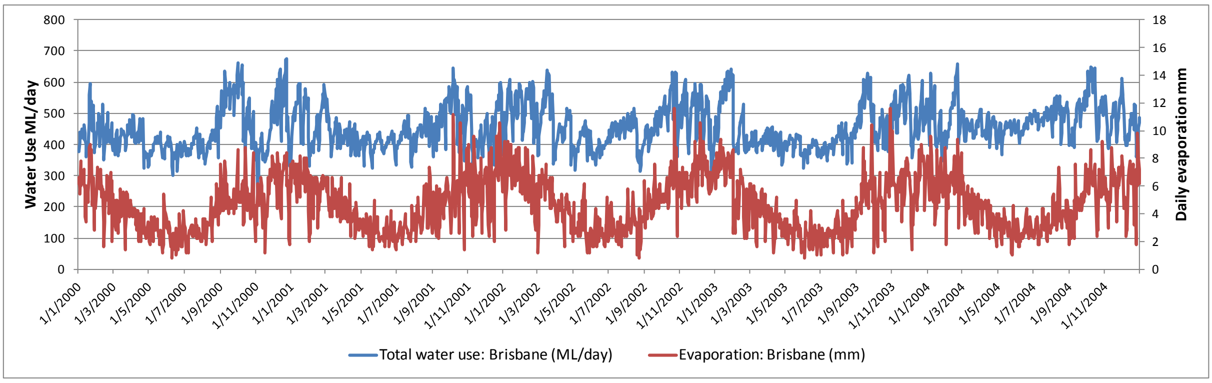


Figure 6. **Brisbane: Daily water use and daily evaporation.**

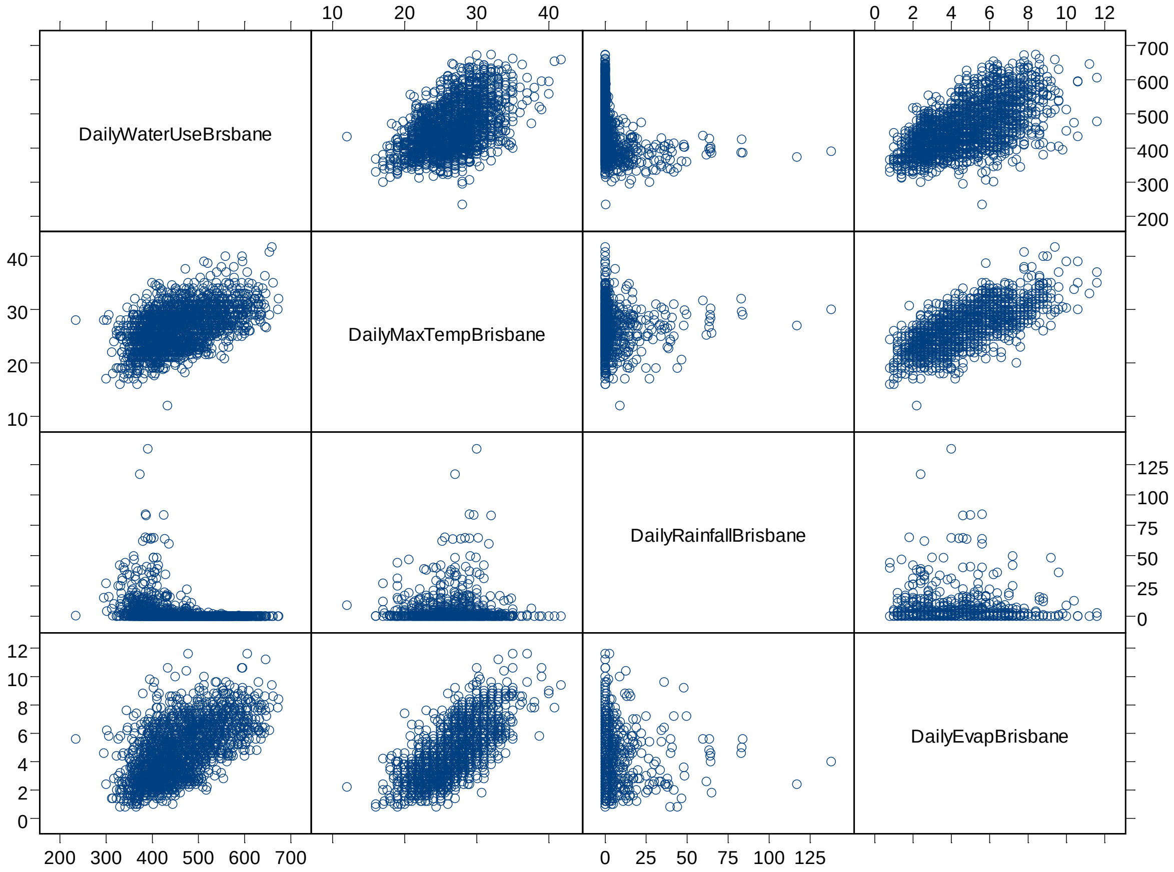


Figure 7. **Brisbane: scatter plots of daily water use, daily rainfall, daily maximum temperature and daily evaporation.**

3. APPLICATION

3.1. Study Area

The study area is SEQ (Figure 8). The area covered by the SEQ is about 22,000 km^2. It contains ten local government areas (see Figure 8). The average annual rainfall in the study area varies from about 1,700 mm in Sunshine Coast to about 1,500 mm in Gold Coast (i.e. from north to south of the study area) (Figure 8 and Table 3) and from about 1,100 mm in Brisbane to about 800 mm in Ipswich (i.e. east to west of the study area) on an average annual basis (Figure 8 and Table 3).

The stochastic simulation method can be applied to an area of any size as long as the input variables can represent the spatial variability and temporal variability of the variables adequately. Since the purpose of the study was to aid the development of TWCM plans at the sub-regional, local government and regional scales, and the household water use data was available for only four local government areas, and the rainfall characteristics exhibited a variation across the region, it was decided to apply the stochastic simulation methodology to four local government areas (LGAs): Brisbane (the capital city), Gold Coast, Sunshine Coast and Ipswich (see Figure 8 for location of these local government areas). Moreton Bay was also chosen, to meet the needs of the objective #2, i.e. to demonstrate how the methodology and outputs of the study can be used to inform the development of Moreton Bay TWCM plan.

Figure 8. **Study area (SEQ) and local government area boundaries.**

Table 3. **Observed average annual rainfall in period 1962 to 2011.**

Local Government Area (LGA)	Average Annual Rainfall (mm)
Brisbane	1129
Moreton Bay	1313
Gold Coast	1454
Sunshine Coast	1676
Ipswich	866

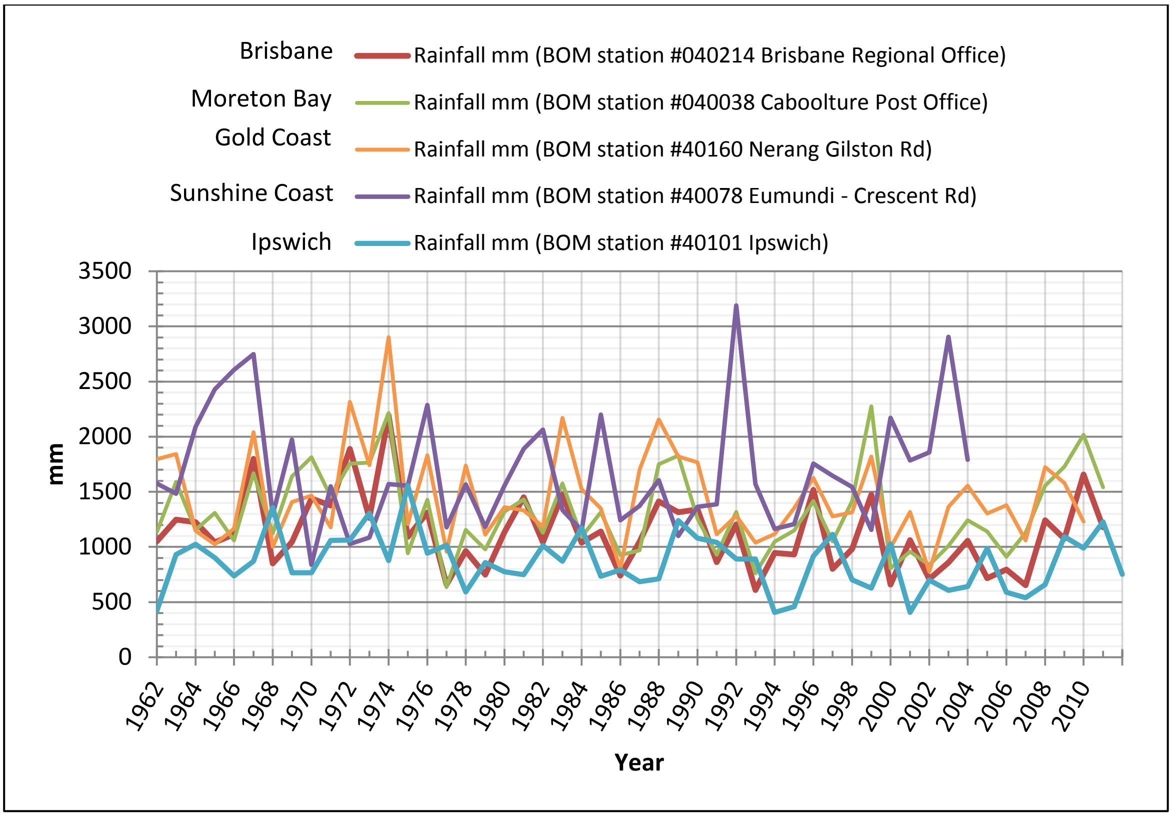


Figure 9. **All LGA: Annual rainfall.**

Table 4. **Availability of data and the data sources.**

Local Government Area	**Data Item**	**Sample Size (Number of Single Family Residential Households)**	**Data Sourced From:**
Brisbane	Tank sizes	5008	Queensland Home and Garden WaterWise Rebate Scheme
Morton Bay	Tank sizes	108[1]	Biermann *et al.* (2012)
Gold Coast	Tank sizes	31	Biermann *et al.* (2012)
Sunshine Coast	Tank sizes	438	Queensland Home and Garden WaterWise Rebate Scheme
Ipswich	Tank sizes	258	Queensland Home and Garden WaterWise Rebate Scheme
Brisbane	Roof area	30[2]	Biermann *et al*. (2012)
Morton Bay	Roof area	108[1]	Biermann *et al.* (2012)
Gold Coast	Roof area	31	Biermann *et al.* (2012)
Sunshine Coast	Roof area	108[1]	Biermann *et al*. (2012)
Ipswich	Roof area	108[1]	Biermann *et al.* (2012)
Brisbane	End use demand	61	Beal and Stewart (2011)
Morton Bay	End use demand	61[3]	Beal and Stewart (2011)
Gold Coast	End use demand	87	Beal and Stewart (2011)
Sunshine Coast	End use demand	67	Beal and Stewart (2011)
Ipswich	End use demand	37	Beal and Stewart (2011)

Notes: [1] The households in Pine Rivers and Caboolture areas were used for Moreton Bay; [2] Roof areas for Brisbane were not available, hence the study used households in Redland, which is an adjacent LGA to Brisbane LGA; [3] water use data was not available for Moreton Bay, hence used Brisbane LGA data.

The essential data required to undertake analysis included tank sizes, connected roof areas and the household water use. The study was limited to new and existing single family residential houses (i.e. detached houses) because the essential data were available for such households only. The sources of the essential data are shown in Figure 9.

The steps involved in applying the stochastic simulation approach to a particular local government area, can be described as follows:

- Development of the Probabilistic Demand model (as described in Chapter 2), to generate plausible household end use demands that were representative for the local government area, over the period of simulation;
- Development of probability distributions for the tank parameters such as tank sizes and roof areas using the data that were representative of the local government area; and
- Simulate the storage and the nutrients (i.e. TP and TN) and sediments (i.e. TSS) mixing behaviour of the water in the rainwater tank using the rainwater tank model (as described in Chapter 2) for the local government area.

The above three steps were repeated for all five LGAs. The results of the application for each LGA are described below, in sections 3.2 to 3.7.

The overall key parameters of the stochastic simulation approach were the period of simulation, the time-step of simulation and the number of iterations that the simulation runs had to be repeated to ensure input variables were adequately sampled.

An insight into the time period of simulation was studied by Liaw and Tsai (2004), which concluded that the impact of time series length on yield estimates was within 3%, for a simulation period of 50 years or more. Hence, we adopted a simulation period of 50 years, from 1 January 1962 to 31 December 2011, for all five LGAs.

An analysis was carried out to examine the time-step of simulation and the number of simulation runs, using the data of Brisbane LGA. This is described in Section 3.2, under the Brisbane analysis. The conclusions of the analysis on the time-step of simulation and number of simulation runs obtained for Brisbane, was applied for all other local government areas.

3.2. Brisbane

3.2.1. Probabilistic Representation of Household Demand

3.2.1.1. Calibration of the Stochastic Demand Model: Input Data

To calibrate the modified SDG model described in Chapter 2 to the Brisbane LGA, household end use water demand data were sourced from Beal and Stewart (2011)’s residential end use measurement study. It provided end use water consumption statistics for 61 single family residential (SFR) households in the Brisbane local government area. The period of measurement was 14 June to 28 June, 2010 (i.e. winter data set) and 1 December 2012 to 21 February 2011 (i.e. summer data set which was an average of three, 2-week periods). Due to the floods in Brisbane in January 2011, 2010 winter data set was considered as more reliable than the 2010/11 summer data set (Beal and Stewart, 2011). Hence we used 2010 winter data set for this study.

The end use water consumption statistics used to calibrate the modified SDG model to Brisbane local government area were event mean volume for toilet, tap, dishwasher and clothes washer end uses in litres/event (Table 5), frequency of event for toilet, tap, shower, bath, dishwasher, clothes washer and garden water use (i.e. irrigation) end uses in events/day (Table 6), shower flow rate in litres/minute (Table 7) and shower duration in minutes (Table 8).

Table 5. **Brisbane: end use event mean volume statistics (data source: Beal and Stewart, 2011).**

Brisbane Statistics	Mean Volume of End Use Event (Litres/Event)				
	Half Flush	Full Flush	Tap	Dishwasher	Clothes Washer
Mean	3.89	7.44	1.19	6.55	99.45
Standard Deviation	1.10	1.58	0.51	8.82	69.06
Skewness	-0.49	1.23	1.18	1.76	1.10

Table 6. **Brisbane: end use frequency statistics (Beal and Stewart, 2011).**

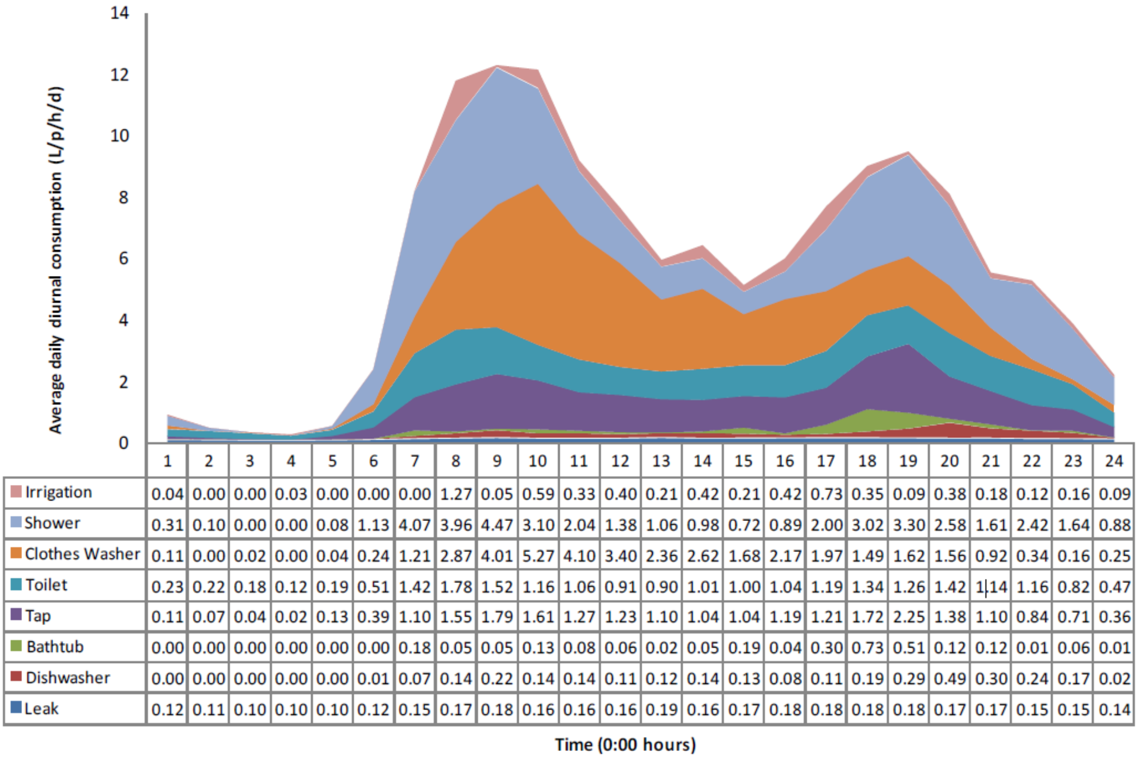
Brisbane Statistics	Frequency (Events Per Day)							
	Half Flush	Full Flush	Tap	Shower	Bath	Dishwasher	Clothes Washer	Irrigation
Mean	4.87	4.21	58.70	2.13	0.13	0.55	0.71	0.12
Standard Deviation	3.97	2.68	33.42	1.99	0.28	0.68	0.56	0.19
Skewness	1.67	1.29	1.13	5.11	2.12	1.94	2.93	1.94

Table 7. **All LGAs: Shower flow rate statistics (data source: Beal and Stewart, 2011).**

Statistics	Shower Event Flow Rate (Litres/Minute)			
	Brisbane	Gold Coast	Sunshine Coast	Ipswich
Mean	7.82	7.79	8.49	7.71
Standard Deviation	3.18	2.21	2.73	3.15
Skewness	2.32	0.43	1.29	0.07

Table 8. **All LGAs: Shower duration statistics (data source: Beal and Stewart, 2011).**

Statistics	Shower End Use Event Durations (Minutes)			
	Brisbane	Gold Coast	Sunshine Coast	Ipswich
Mean	5.72	5.72	6.45	5.79
Standard Deviation	2.22	2.22	2.72	2.25
Skewness	1.23	1.23	0.87	0.94



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Irrigation	0.04	0.00	0.00	0.03	0.00	0.00	0.00	1.27	0.05	0.59	0.33	0.40	0.21	0.42	0.21	0.42	0.73	0.35	0.09	0.38	0.18	0.12	0.16	0.09
Shower	0.31	0.10	0.00	0.00	0.08	1.13	4.07	3.96	4.47	3.10	2.04	1.38	1.06	0.98	0.72	0.89	2.00	3.02	3.30	2.58	1.61	2.42	1.64	0.88
Clothes Washer	0.11	0.00	0.02	0.00	0.04	0.24	1.21	2.87	4.01	5.27	4.10	3.40	2.36	2.62	1.68	2.17	1.97	1.49	1.62	1.56	0.92	0.34	0.16	0.25
Toilet	0.23	0.22	0.18	0.12	0.19	0.51	1.42	1.78	1.52	1.16	1.06	0.91	0.90	1.01	1.00	1.04	1.19	1.34	1.26	1.42	1|14	1.16	0.82	0.47
Tap	0.11	0.07	0.04	0.02	0.13	0.39	1.10	1.55	1.79	1.61	1.27	1.23	1.10	1.04	1.04	1.19	1.21	1.72	2.25	1.38	1.10	0.84	0.71	0.36
Bathtub	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.05	0.05	0.13	0.08	0.06	0.02	0.05	0.19	0.04	0.30	0.73	0.51	0.12	0.12	0.01	0.06	0.01
Dishwasher	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.14	0.22	0.14	0.14	0.11	0.12	0.14	0.13	0.08	0.11	0.19	0.29	0.49	0.30	0.24	0.17	0.02
Leak	0.12	0.11	0.10	0.10	0.10	0.12	0.15	0.17	0.18	0.16	0.16	0.16	0.19	0.16	0.17	0.18	0.18	0.18	0.18	0.17	0.17	0.15	0.15	0.14

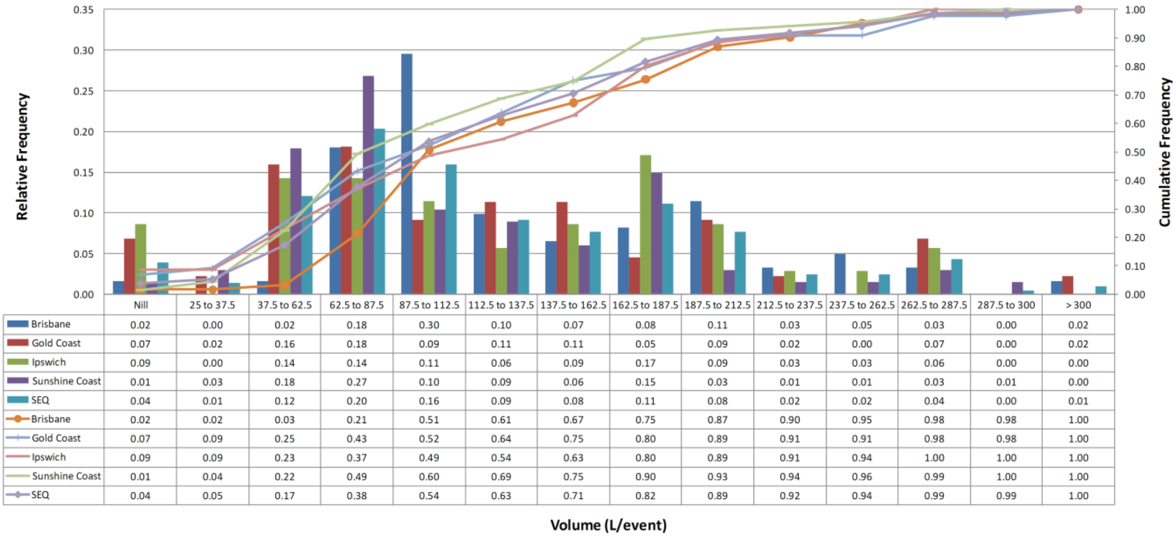
Figure 10. Brisbane: average daily diurnal pattern (data source: Beal and Stewart, 2011).

Table 9. All LGAs: Probability distributions used for each end uses in different LGAs.

End Use Probability Distribution	Original SDG (Duncan and Mitchell, 2008)	Modified Distribution			
		Brisbane	Gold Coast	Sunshine Coast	Ipswich
Toilet volume	Normal	Normal	Normal	Log-normal	Normal
Toilet Frequency	Fixed value	Normal	Normal	Log-normal	Normal
Clothes washer volume	Fixed value	Observed PDF[1]	Observed PDF	Observed PDF	Observed PDF
Dishwasher volume	Fixed value	Observed PDF	Observed PDF	Observed PDF	Observed PDF
Tap volume	Fixed value	Normal	Normal	Log-normal	Log-normal
Bathtub volume	Fixed value	Fixed value	Fixed value	Fixed value	Fixed value
Bathtub flow rate	Fixed value	Fixed value	Fixed value	Fixed value	Fixed value
Shower flow rate	Log-normal	Normal	Normal	Log-normal	Normal
Irrigation flow rate	Normal	Normal	Normal	Normal	Normal

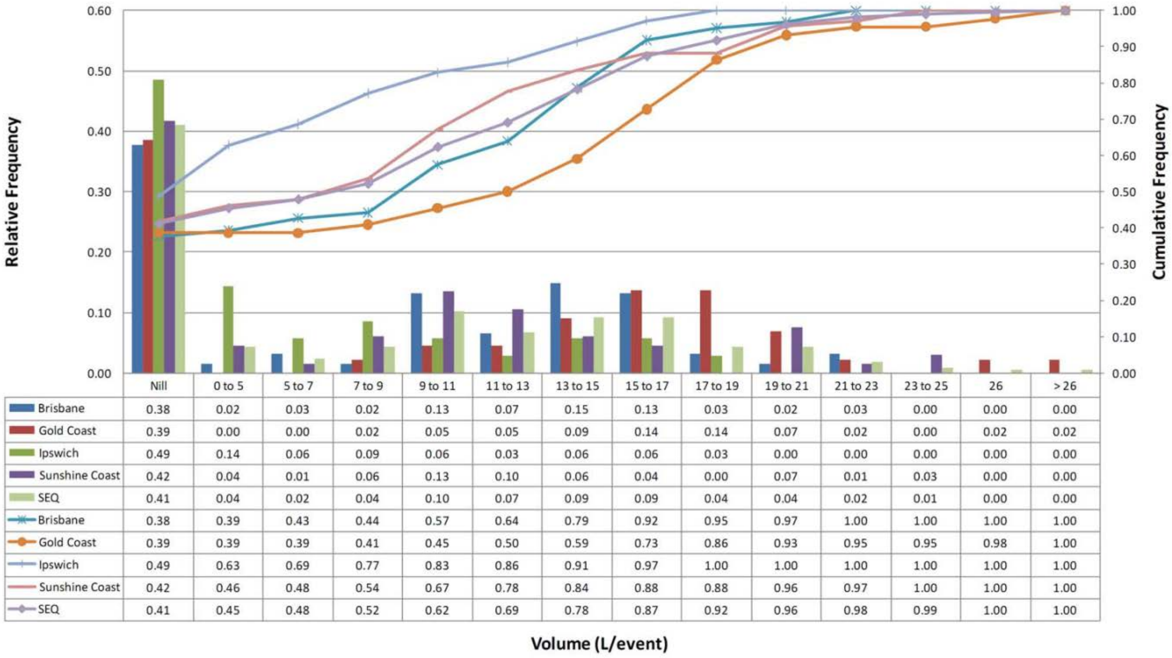
Note #1: the Observed PDF if the Probability Distribution Function constructed from the observed data, which was derived from the cumulative frequencies given in Figure 11 and Figure 12.

The diurnal pattern was used to generate probabilities for triggering events for each end use (Figure 10). The probability distributions for each end use were found through calibration). For most end uses either normal or log-normal distribution was used (Table 9). The distribution was chosen through calibration rather than fitting of observed data to probability distributions. This was because our study and the study of Beal and Stewart (2011) were undertaken in parallel and therefore, the data available to this study was in a form of descriptive statistics rather than individual data values. For clothes washer and dishwasher end uses, the probability distributions of the observed data (i.e. cumulative frequency distributions of the volume and frequency of use of clothes washers and dishwasher are shown in Figure 11, Figure 12, Figure 13 and Figure 14 respectively) were used as per the modified method described in section 2.2.3.



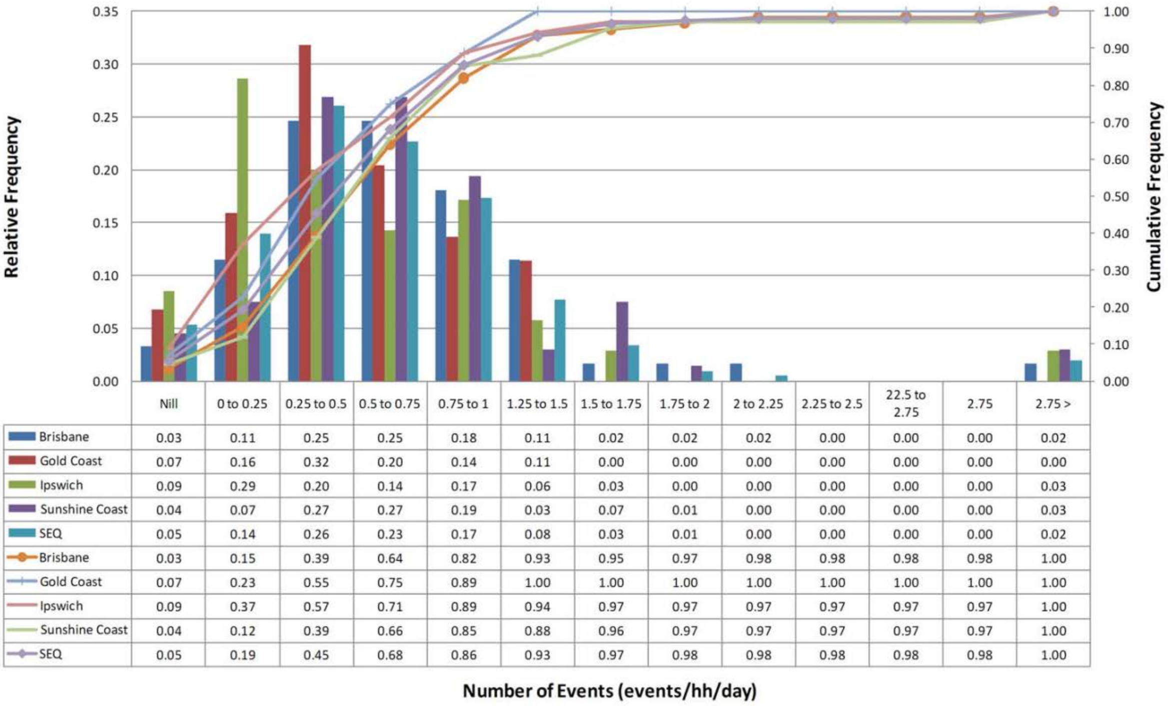
	Nill	25 to 37.5	37.5 to 62.5	62.5 to 87.5	87.5 to 112.5	112.5 to 137.5	137.5 to 162.5	162.5 to 187.5	187.5 to 212.5	212.5 to 237.5	237.5 to 262.5	262.5 to 287.5	287.5 to 300	> 300
■ Brisbane	0.02	0.00	0.02	0.18	0.30	0.10	0.07	0.08	0.11	0.03	0.05	0.03	0.00	0.02
■ Gold Coast	0.07	0.02	0.16	0.18	0.09	0.11	0.11	0.05	0.09	0.02	0.00	0.07	0.00	0.02
■ Ipswich	0.09	0.00	0.14	0.14	0.11	0.06	0.09	0.17	0.09	0.03	0.03	0.06	0.00	0.00
■ Sunshine Coast	0.01	0.03	0.18	0.27	0.10	0.09	0.06	0.15	0.03	0.01	0.01	0.03	0.01	0.00
■ SEQ	0.04	0.01	0.12	0.20	0.16	0.09	0.08	0.11	0.08	0.02	0.02	0.04	0.00	0.01
─●─ Brisbane	0.02	0.02	0.03	0.21	0.51	0.61	0.67	0.75	0.87	0.90	0.95	0.98	0.98	1.00
─┼─ Gold Coast	0.07	0.09	0.25	0.43	0.52	0.64	0.75	0.80	0.89	0.91	0.91	0.98	0.98	1.00
── Ipswich	0.09	0.09	0.23	0.37	0.49	0.54	0.63	0.80	0.89	0.91	0.94	1.00	1.00	1.00
── Sunshine Coast	0.01	0.04	0.22	0.49	0.60	0.69	0.75	0.90	0.93	0.94	0.96	0.99	1.00	1.00
─◆─ SEQ	0.04	0.05	0.17	0.38	0.54	0.63	0.71	0.82	0.89	0.92	0.94	0.99	0.99	1.00

Figure 11. **All LGAs: observed cumulative frequencies for clothes washer volume (source: Beal and Stewart, 2011).**



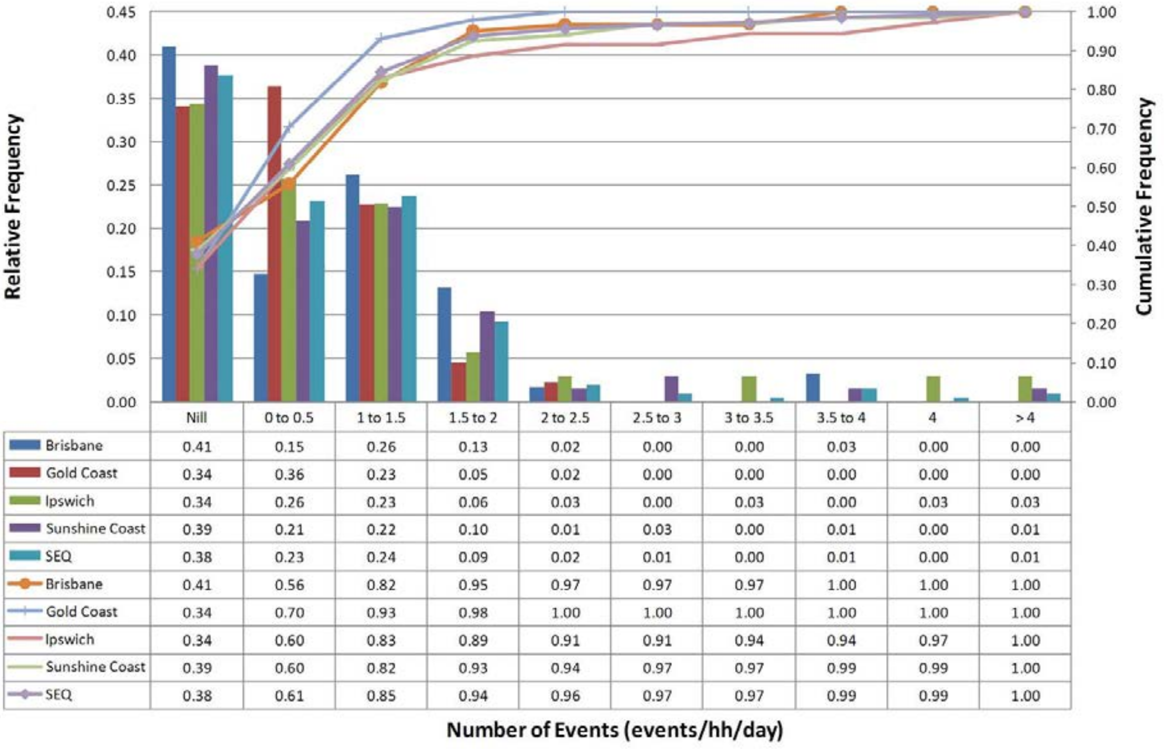
	Nill	0 to 5	5 to 7	7 to 9	9 to 11	11 to 13	13 to 15	15 to 17	17 to 19	19 to 21	21 to 23	23 to 25	26	> 26
■ Brisbane	0.38	0.02	0.03	0.02	0.13	0.07	0.15	0.13	0.03	0.02	0.03	0.00	0.00	0.00
■ Gold Coast	0.39	0.00	0.00	0.02	0.05	0.05	0.09	0.14	0.14	0.07	0.02	0.00	0.02	0.02
■ Ipswich	0.49	0.14	0.06	0.09	0.06	0.03	0.06	0.06	0.03	0.00	0.00	0.00	0.00	0.00
■ Sunshine Coast	0.42	0.04	0.01	0.06	0.13	0.10	0.06	0.04	0.00	0.07	0.01	0.03	0.00	0.00
■ SEQ	0.41	0.04	0.02	0.04	0.10	0.07	0.09	0.09	0.04	0.04	0.02	0.01	0.00	0.00
─✳─ Brisbane	0.38	0.39	0.43	0.44	0.57	0.64	0.79	0.92	0.95	0.97	1.00	1.00	1.00	1.00
─●─ Gold Coast	0.39	0.39	0.39	0.41	0.45	0.50	0.59	0.73	0.86	0.93	0.95	0.95	0.98	1.00
─┼─ Ipswich	0.49	0.63	0.69	0.77	0.83	0.86	0.91	0.97	1.00	1.00	1.00	1.00	1.00	1.00
── Sunshine Coast	0.42	0.46	0.48	0.54	0.67	0.78	0.84	0.88	0.88	0.96	0.97	1.00	1.00	1.00
─◆─ SEQ	0.41	0.45	0.48	0.52	0.62	0.69	0.78	0.87	0.92	0.96	0.98	0.99	1.00	1.00

Figure 12. **All LGAs: observed cumulative frequencies for dishwasher volume (source: Beal and Stewart, 2011).**



	Nill	0 to 0.25	0.25 to 0.5	0.5 to 0.75	0.75 to 1	1.25 to 1.5	1.5 to 1.75	1.75 to 2	2 to 2.25	2.25 to 2.5	22.5 to 2.75	2.75	2.75 >
Brisbane	0.03	0.11	0.25	0.25	0.18	0.11	0.02	0.02	0.02	0.00	0.00	0.00	0.02
Gold Coast	0.07	0.16	0.32	0.20	0.14	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ipswich	0.09	0.29	0.20	0.14	0.17	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.03
Sunshine Coast	0.04	0.07	0.27	0.27	0.19	0.03	0.07	0.01	0.00	0.00	0.00	0.00	0.03
SEQ	0.05	0.14	0.26	0.23	0.17	0.08	0.03	0.01	0.00	0.00	0.00	0.00	0.02
Brisbane	0.03	0.15	0.39	0.64	0.82	0.93	0.95	0.97	0.98	0.98	0.98	0.98	1.00
Gold Coast	0.07	0.23	0.55	0.75	0.89	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ipswich	0.09	0.37	0.57	0.71	0.89	0.94	0.97	0.97	0.97	0.97	0.97	0.97	1.00
Sunshine Coast	0.04	0.12	0.39	0.66	0.85	0.88	0.96	0.97	0.97	0.97	0.97	0.97	1.00
SEQ	0.05	0.19	0.45	0.68	0.86	0.93	0.97	0.98	0.98	0.98	0.98	0.98	1.00

Figure 13. **LGAs: observed cumulative frequencies for clothes washer frequency of use (source: Beal and Stewart, 2011).**



	Nill	0 to 0.5	1 to 1.5	1.5 to 2	2 to 2.5	2.5 to 3	3 to 3.5	3.5 to 4	4	> 4
Brisbane	0.41	0.15	0.26	0.13	0.02	0.00	0.00	0.03	0.00	0.00
Gold Coast	0.34	0.36	0.23	0.05	0.02	0.00	0.00	0.00	0.00	0.00
Ipswich	0.34	0.26	0.23	0.06	0.03	0.00	0.03	0.00	0.03	0.03
Sunshine Coast	0.39	0.21	0.22	0.10	0.01	0.03	0.00	0.01	0.00	0.01
SEQ	0.38	0.23	0.24	0.09	0.02	0.01	0.00	0.01	0.00	0.01
Brisbane	0.41	0.56	0.82	0.95	0.97	0.97	0.97	1.00	1.00	1.00
Gold Coast	0.34	0.70	0.93	0.98	1.00	1.00	1.00	1.00	1.00	1.00
Ipswich	0.34	0.60	0.83	0.89	0.91	0.91	0.94	0.94	0.97	1.00
Sunshine Coast	0.39	0.60	0.82	0.93	0.94	0.97	0.97	0.99	0.99	1.00
SEQ	0.38	0.61	0.85	0.94	0.96	0.97	0.97	0.99	0.99	1.00

Figure 14. **LGAs: observed cumulative frequencies for dishwasher frequency of use (source: Beal and Stewart, 2011).**

As mentioned earlier, the time-period of simulation for all five LGAs was 1 January 1962 to 31 December 2011 (50 years). The climate data required for the SDG model was daily maximum temperature. This was to determine the garden water use. The rainfall distribution during the simulation period (Figure 15) and daily maximum temperature (Figure 16) were obtained from Brisbane Regional Office (station no. 40214). Calibration of the modified SDG model involved generating a sufficient number of demand time series (or profiles) and compare modelled statistics of each end use with the corresponding observed values. For this analysis, we generated 3,000 demand profiles.

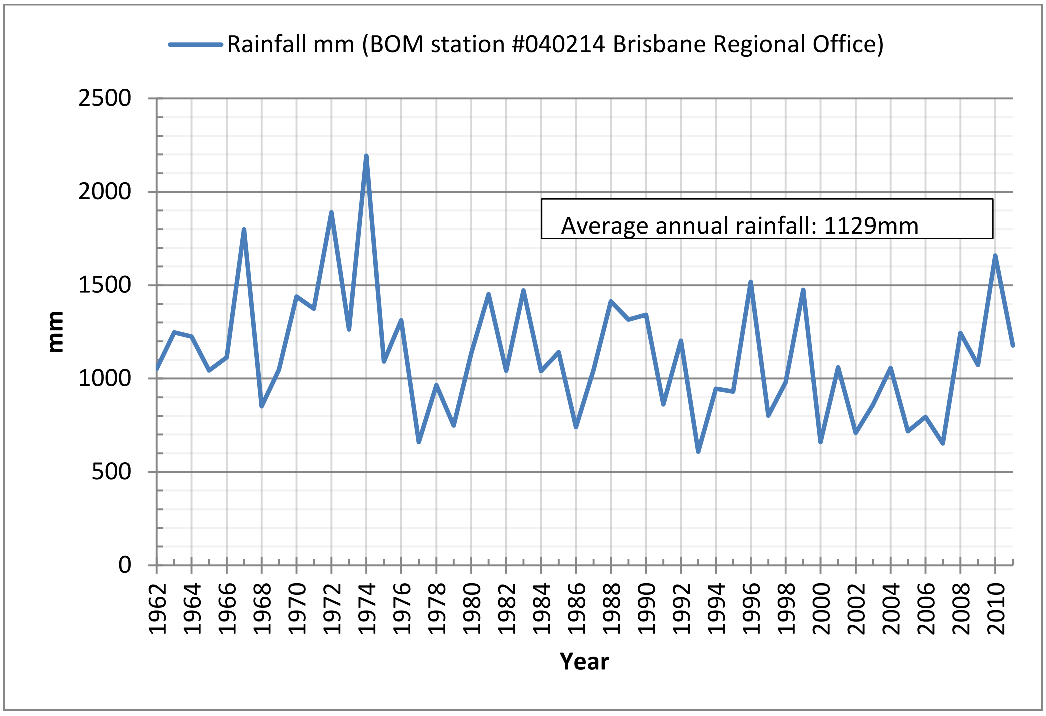


Figure 15. **Brisbane: Annual Rainfall 1962-2011 (data source: Brisbane Regional Office, station no. 40214).**

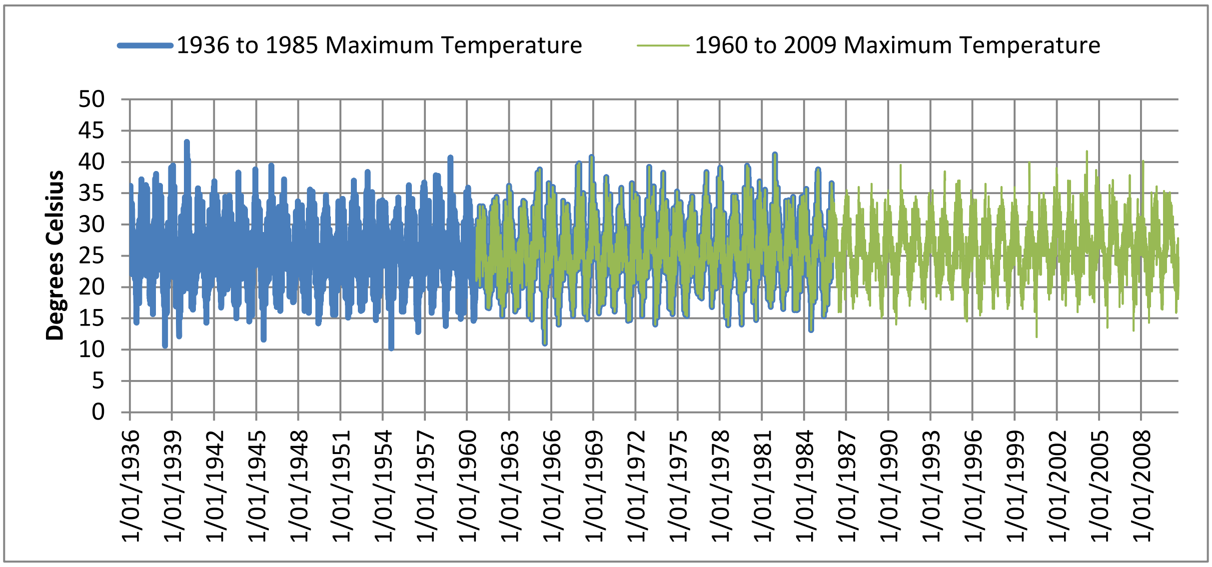


Figure 16. **Brisbane: Daily Maximum temperature for (data source: Brisbane Regional Office, station no. 40214).**

3.2.1.2. Calibration of the Stochastic Demand Model: Results

The observed and the modelled demand of each end use were compared in terms of mean, standard deviation, minimum value and maximum value, of each end use in litres/person/day (see Table 10), total water use and end use breakdown (Figure 17) and the frequency distribution of each end use and the total water use (Figure 18). These results indicated a reasonably good calibration of the SDG model.

During the calibration, we paid attention to toilet, clothes washer and irrigation end uses (i.e. to obtain the modelled frequency distribution of these end uses match with the observed frequency distributions as closely as possible) because they were the end uses being supplemented with rainwater as per Queensland Development Code 3.2. The frequency distributions of toilet, clothes washer and irrigation demands are shown in Figure 18.

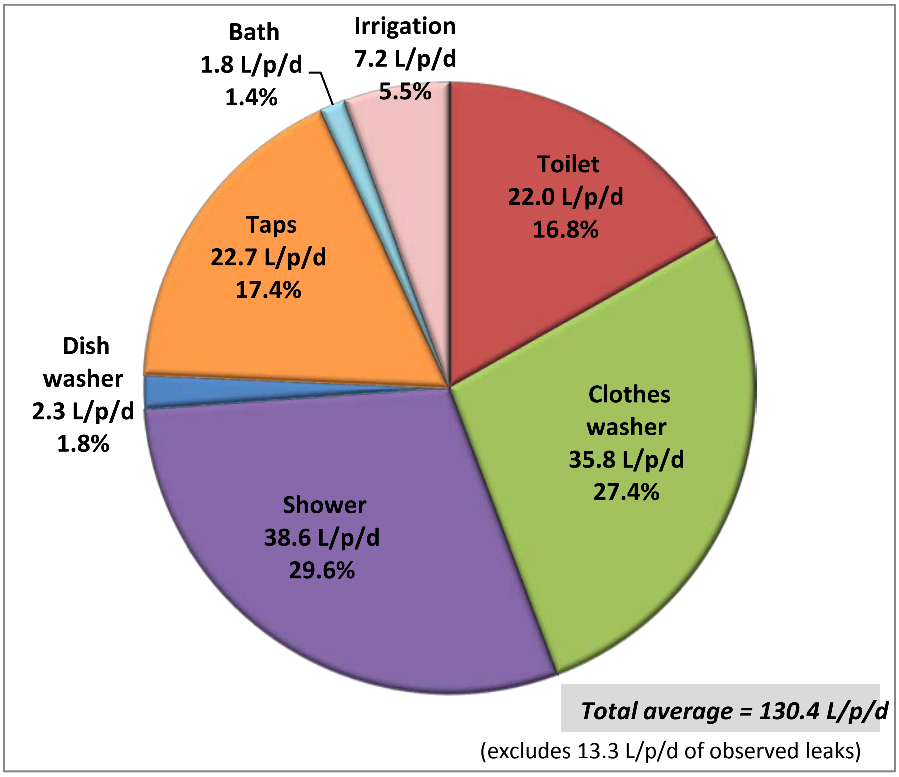
The average household consumption during the measured period (i.e. 14-28 June 2010) without considering leaks was 130.4 L/p/d. The simulated or modelled value of household consumption was 134.6 L/p/d. Comparison of the observed and modelled end use breakdown indicated that modelled demands were of similar order of magnitude to the observed demands (see Table 10).

Upon calibrating the SDG model, 1,000 probable demand time series of 50 years were generated for each end use, in one minute time scale. These were then aggregated to match with the time-step of simulation of rainwater tank simulation and used as probable values for the input variable on ‘demand’ in the rainwater tank model.

Table 10. **Brisbane: observed and modelled household end use demands.**

	Household End Use Water Demand in Litres/Person/Day							
	Toilet	**Clothes Washer**	**Shower**	**Dishwasher**	**Tap**	**Bathtub**	**Irrigation[1]**	**Total**
Observed Mean	21.96	35.76	38.63	2.33	22.72	1.78	7.21	130.4
Modelled Mean	20.06	38.76	38.41	2.37	27.44	1.10	6.46	134.60
Observed Standard Deviation	11.96	20.7	20.92	2.54	11.41	3.85	17.39	55.08
Modelled Standard Deviation	10.058	36.70	14.96	4.31	11.49	0.02	6.50	42.87
Observed Min	3.7	3.1	9.4	0.0	3.2	0.0	0.0	31.9
Modelled Min	0.00	0.00	0.00	0.00	0.00	1.02	0.00	1.02
Observed Max	75.5	110.2	112.5	10.7	61.5	18.2	114.8	283.0
Modelled Max	60.01	347.64	91.91	32.10	73.46	1.20	36.56	606.32

Note 1: The measured data on irrigation event duration and flow rates were not reliable due to small sample size (Beal and Stewart, 2012)



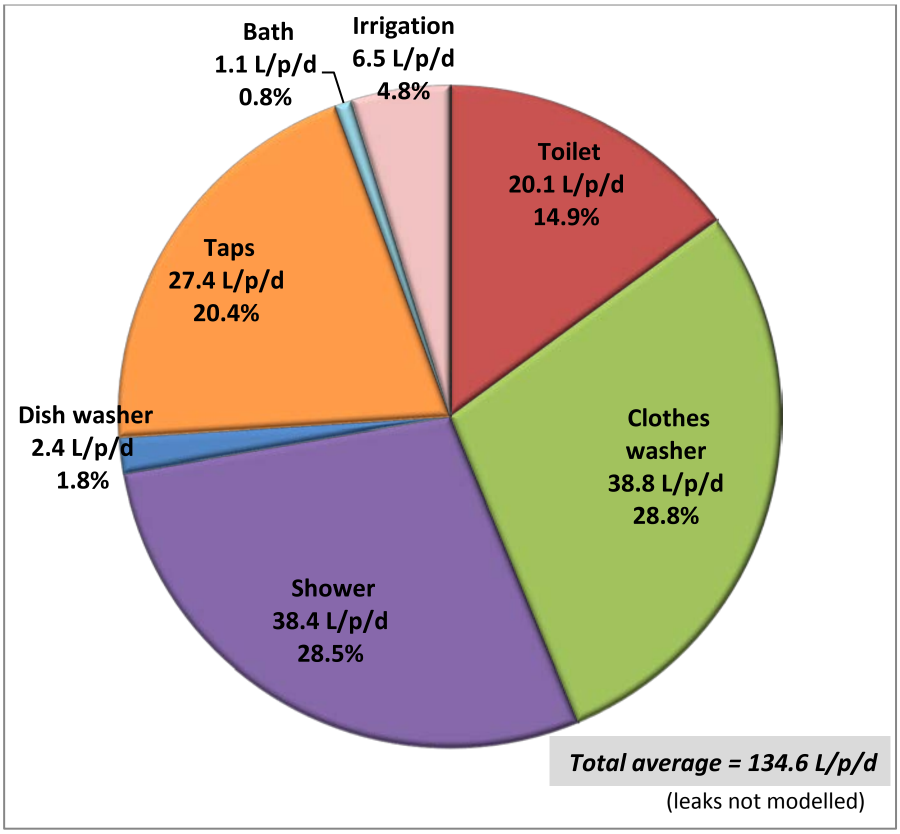


Figure 17. **Brisbane: comparison of observed (top) and modelled (bottom) average per capita water end use.**

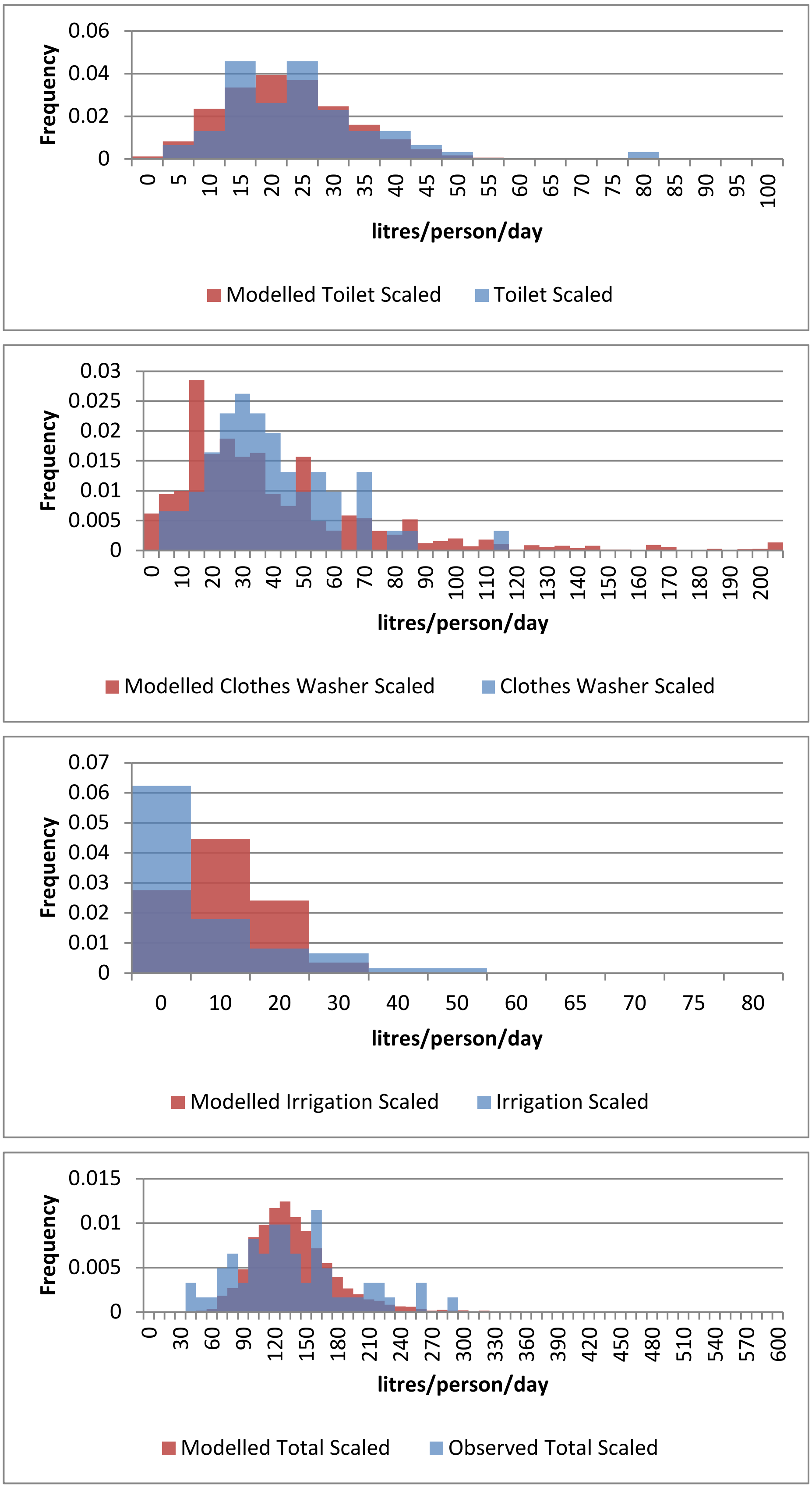


Figure 18. **Brisbane: comparison of frequency distributions of observed and modelled toilet, clothes washer, irrigation and total, per capita water use.**

3.2.2. Probabilistic Representation of Rainwater Tank Sizes

Tank sizes (i.e. tank volumes) were sourced from the Home and garden Waterwise Rebate Scheme (HWRS). The data sample contained 5,008 tanks and their nominal sizes.

The sizes of rainwater tanks used in the stochastic simulation were effective tank sizes, rather than the nominal tank sizes. The effective tank size was the volume of water hold in a tank between the outlet and the overflow valves. The tank sizes reported in Biermann *et al.* (2012) did not comprised the tank sizes for Brisbane local government area, but included both nominal and effective tank sizes for Caboolture, Redlands, Pine Rivers and Gold Coast areas. A relationship between effective and nominal tank sizes was derived using the data given in Biermann *et al.* (2012), which was then applied to Brisbane's nominal tank sizes obtained the HWRS. The relationship was in the following form:

Effective tank size = 0.89 X Nominal tank size

The effective sizes of tanks in this sample ranged from 2.66 kL to 30.56 kL (Figure 19), with a mean of 4.4 kL and a standard deviation of 2.69 kL (see Appendix A for descriptive statistics).

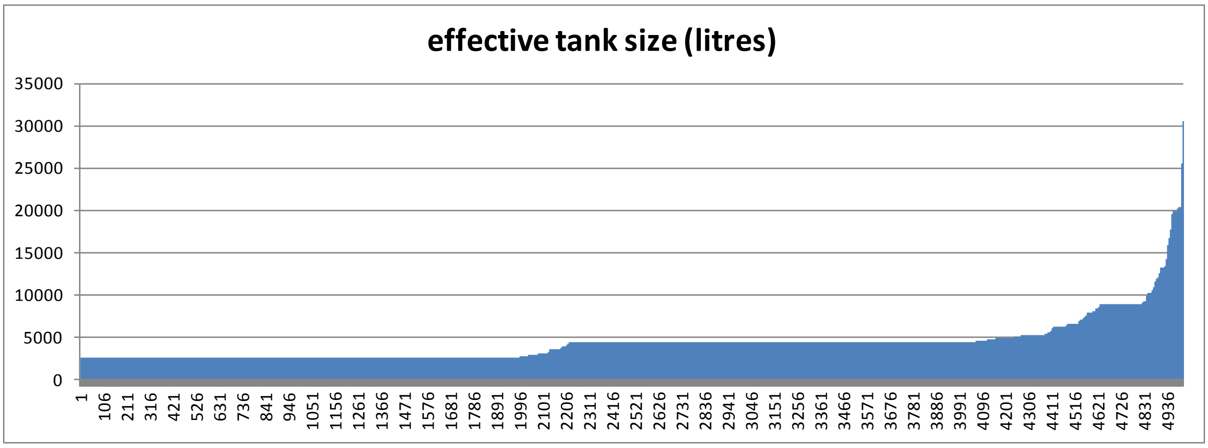


Figure 19. **Brisbane: Tank sizes.**

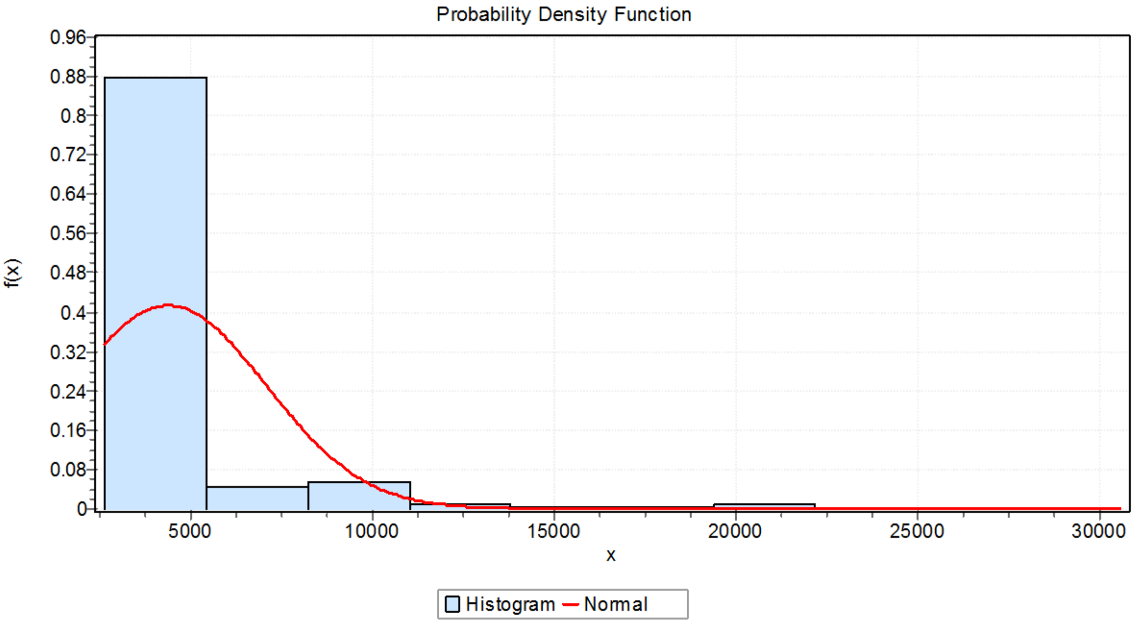


Figure 20. **Brisbane: Fitting tank size data to the normal distribution (X axis represents tank sizes in litres).**

A key limitation of the rainwater tank model (Mitchell *et al.*, 2008) used in the study was that it allowed only the use of normal distribution for both tank sizes and roof areas. Accordingly, we assumed the normal distribution for both tank sizes and roof areas. However, we examined the acceptability of the normal distribution using Easy Fit Professional (2010), in order to understand how the observed data deviated from the normal distribution. This involved: (a) examining the goodness of fit of the observed data of tank size and roof area, to a number of probability distributions (including the normal distribution) using Kolmogorov-Smirnov, Anderson-Darling and Chi-square goodness of fit tests (see Appendix A for fitting results); and (b) plotting the frequency distribution of the observed data against the normal probability distribution for visual understanding of the deviation of observed data from the normal distribution (Figure 20). Future studies should consider modifying the rainwater tank model used in this study to incorporate any user-defined probability distribution function.

The goodness of fit analysis indicated that the observed tank sizes were not normally distributed (Kolmogorov-Smirnov statistic and P-value = 0.29248, 0 respectively; Chi-Squared statistic, DF and P-value = 11162.0, 12, 0 respectively; see Appendix A for details). Deviation of the observed data on tank sizes from the normal distribution is shown in Figure 20. The consequence of this limitation was generation of a higher proportion of 5-10 kL tanks and a lower proportion of 4-5 kL tanks, than the observed sample, during the stochastic simulation.

3.2.3. Probabilistic Representation of Roof Areas

Data on connected roof areas to tanks were not available for Brisbane. It was assumed that roof areas available for Redlands (from Biermann *et al*., 2012), would be a representative sample for Brisbane because of Brisbane and Redlands were adjacent local government areas.

The data sample from Redlands LGA consisted of thirty data points (see Appendix A for descriptive statistics). Roof areas in the data sample varied from 25 m^2 to 260 m^2, with a mean of 111.6 m^2 and a standard deviation of 47.14 m^2 (Figure 21). The roof areas available for Caboolture and Pine Rivers could have been used for Brisbane on the basis that these areas were located in an adjacent LGA to Brisbane, but we kept Caboolture and Pine Rivers data to undertake Moreton Bay LGA analysis.

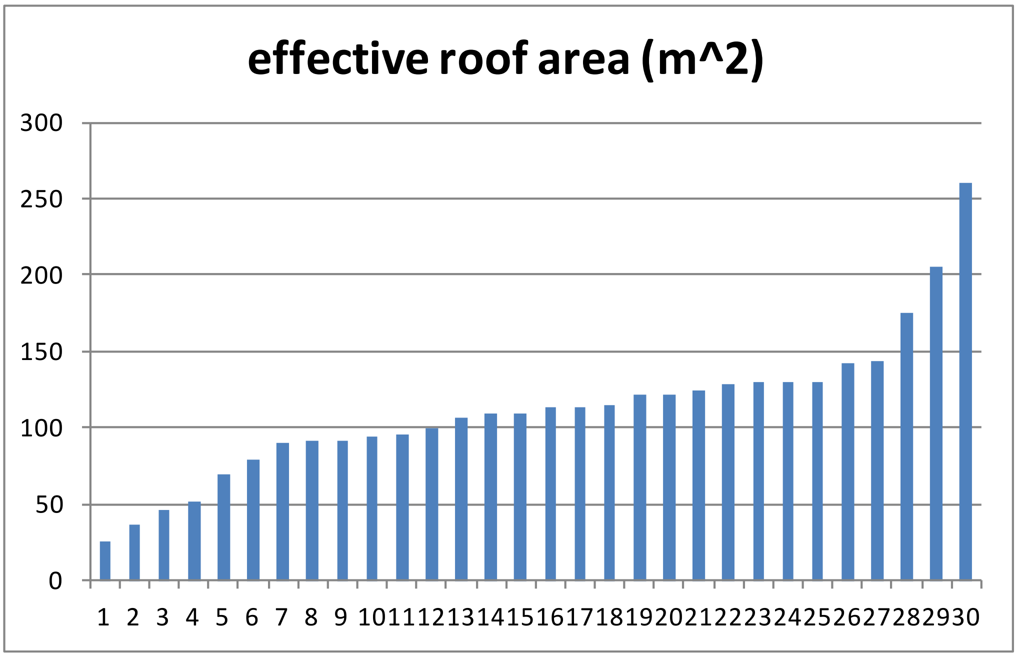


Figure 21. **Brisbane: Roof sizes (source: Biermann *et al.*, 2012).**

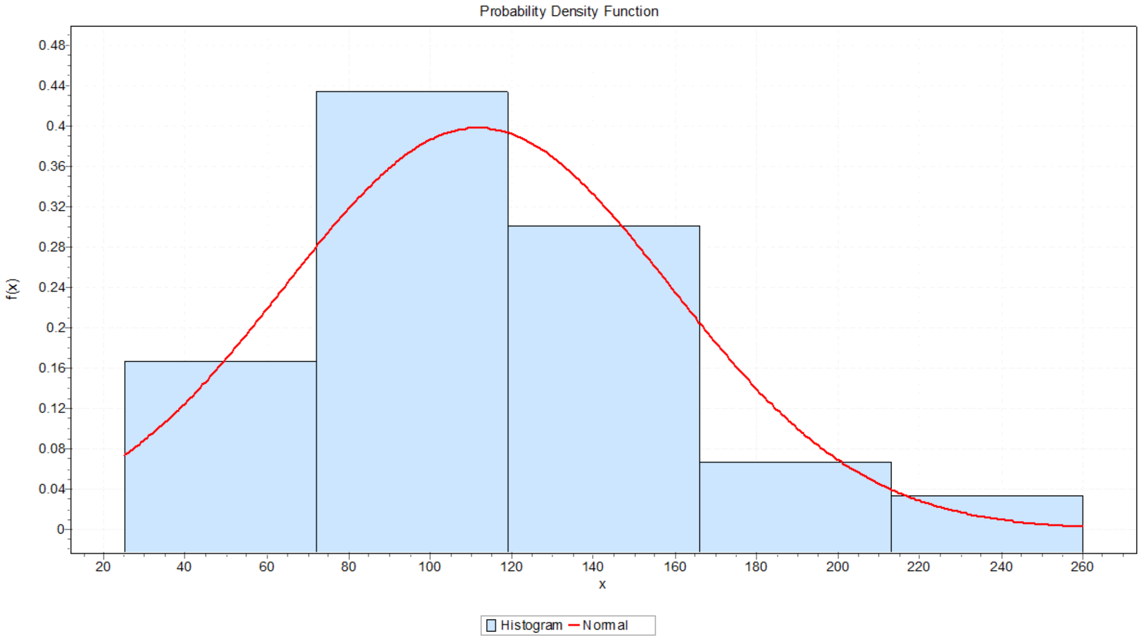


Figure 22. **Brisbane: Fitting roof area data to the normal distribution (X axis represents roof area in m^2).**

Similar to tank sizes, the roof area variable in the rainwater tank model allowed the use of normal distribution only. Accordingly, normal distribution was assumed for roof areas. However, as mentioned above, the acceptability of the normal distribution was examined using Easy Fit Professional (2010), in order to understand how the observed data deviated from the normal distribution.

The goodness of fit analysis indicated that the observed roof areas were normally distributed (Kolmogorov-Smirnov statistic and P-value = 0.18174, 0.24, respectively; Chi-Squared statistic, DF and P-value = 3.0809, 3, 0.38, respectively; see Appendix A for details). Fitting of the observed data on roof areas to the normal distribution is shown in Figure 22.

3.2.4. Time-Step of Tank Simulation

One of the key parameters of the simulation was the time-step of simulation. Coombes and Barry (2007) and Mitchell *et al*. (2008) showed that time-step of simulation could introduce an error to the amount of water supply from a tank, if an incorrect time-step was used for the simulation of storage behaviour. For a tank with a trickle supply from the mains, they recommended a 6-minutes and/or hourly time-step.

In SEQ however, while trickle supply from mains was an acceptable solution under QDC MP 4.2, the preferred approach was to install a valve to switch water supply from rainwater to mains water if the rainwater tank was empty (Queensland Development Code, 2008). Since this approach would not allow water in the tank to vary significantly during a single day, some researchers used daily time-step, for the rainwater tank simulation, in particular to study the effect of spatial lumping on the supply of water from the tank (Xu *et al*., 2010; Maheepala *et al*., 2011; Mashford *et al*., 2011; Neumann *et al*., 2011 and Coultas *et al*., 2011).

Given that there were different views on the time-step of simulation, and our interest was not only to study the effect of spatial lumping, but also to provide robust estimates for the supply from rainwater tanks to inform long-term supply and demand planning as well as TWCM planning, it was decided to examine the effect of hourly and daily simulation time-step on the tank supply and overflow.

Brisbane LGA was chosen to examine the effect of hourly and daily simulation time-step on the tank supply and overflow. There was no particular reason for this selection and any of the local government areas could have been chosen.

Both hourly and daily rainfall, daily evaporation and daily maximum temperature data were available for the period 1/1/1936 to 31/12/1985 from the Brisbane Regional Office (station no. 40214). Hence, 1/1/1936 to 31/12/1985 was used examine the appropriate time-step of simulation. The rainfall time series during this period is shown in Figure 23.

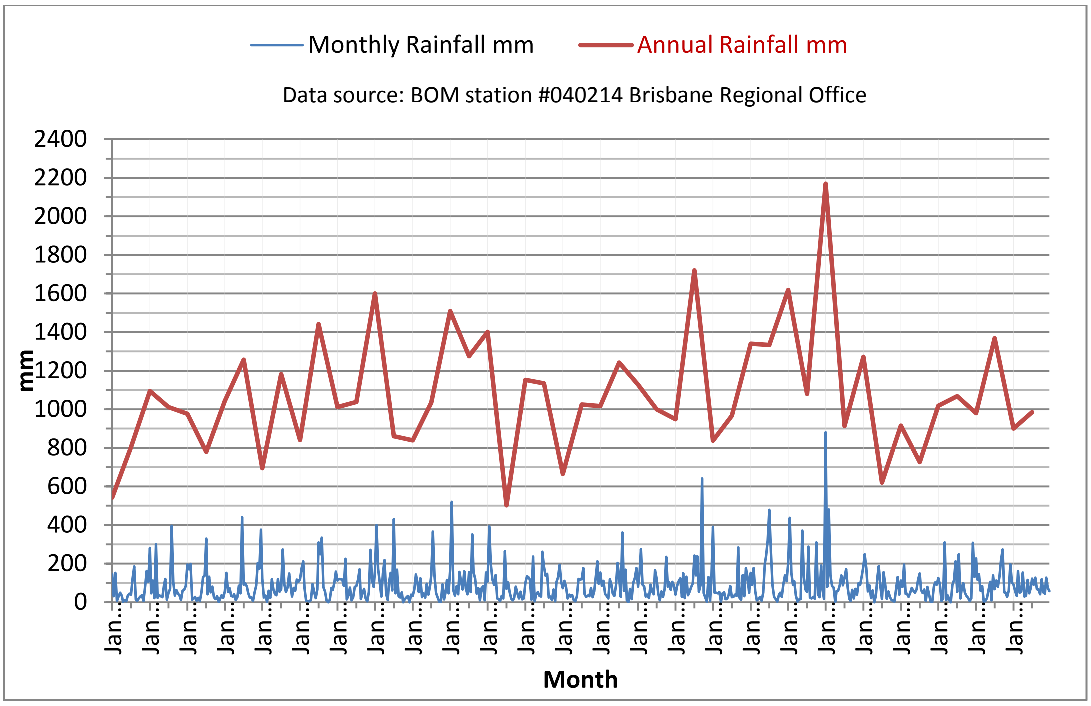


Figure 23. **Brisbane: rainfall during simulation period 1936-1985.**

Table 11. **Brisbane: Input parameter values of the rainwater tank model.**

	Tank Size	Effective Roof Area	Initial Loss[1]	Continuing Loss[1]
Units	**kL**	**m^2**	**mm**	**%**
Observed minimum	2.66	25.00	0	0
Observed Mean	4.4	111.63	0.5	15
Observed maximum	30.56	260.00	1.75	30
Probability distribution	Normal	Normal	Normal	Normal
Coefficient of Variation	0.6114	0.4223	1	0.333
Standard Deviation	2.69	47.14	0.5	5
Sample size	5008	30	0[1]	0[1]

Note #1: data not available for Brisbane. Used Melbourne-based data reported in Xu *et al*. (2010).

Storage behaviour of a rainwater tank was simulated on an hourly basis and a daily basis to understand the effect of hourly and daily time-step on the tank supply and overflow. The input parameters used for this analysis is shown in Table 11. These parameters were determined through the analysis of tank sizes and roof areas in Brisbane local government area, as described in sections 3.2.2 and 3.2.3. Each case, i.e. hourly and daily simulation cases, was executed for 10,000 iterations, by sampling tank sizes, roof areas and roof losses from the distributions of the input variables. Household demand was sampled from the 1,000 demand profiles generated using the SDG model described in section 3.2.1.

The outputs of the simulation were hourly and daily supply and overflow from the tank, recorded over the simulation period, i.e. 1936-1985, for 10,000 iterations. The outputs were aggregated and processed in terms of average annual supply and average annual overflow over the simulation period, which resulted in 10,000 points of average annual supply and average annual overflow values, computed on an hourly and a daily basis. The mean value of the 10,000 data points corresponding to hourly and daily analysis were then compared (Table 12).

Table 12. **Brisbane: overflow and yield results of daily and hourly simulations.**

Simulation Case	Tank Yield in kL/hh/yr	Overflow in kL/hh/yr
Daily stochastic simulation	43.64	64.40
Hourly stochastic simulation	42.49	49.25
Difference, compared to hourly stochastic simulation	2.7%	30.7%

The comparison of hourly and daily simulation results indicated that the use of a daily time-step for the behavioural analysis of rainwater tanks had an overestimation effect on both supply and overflow from the tank, compared to the use of an hourly time-step for the behavioural analysis of rainwater tanks. However, in terms of the magnitude, the yield was only 2.7% overestimated while the overflow was about 30% overestimated.

Therefore, the conclusion was that for yield studies comparable results could be obtained by undertaking behavioural simulation of tank storage on a daily basis. However, for the accurate quantification of tank overflow and associated implications such as contaminant discharges to waterways, it was desirable to use an hourly time-step.

As stated in Chapter 1, the objectives of the study were to understand the effect of spatial lumping on water quantity and quality implications and quantify the supply from rainwater tanks in absolute terms. The first objective needed to be assessed on relative terms rather than on absolute terms. Hence, the effect of time-step of the simulation was not relevant. The second objective focussed on the supply from a tank, for which the error was 2.7% overestimation of supply, compared to the yield obtained with hourly simulation, which was considered as not significant to warrant hourly stochastic simulation over daily stochastic simulation. This was because unlike deterministic simulation, stochastic simulation required many runs of simulation to ensure adequate sampling from input variables. Thus hourly simulation would take much more computer time and data processing time than the daily simulation.

Therefore, it was concluded that the daily time-step was appropriate for this study. Hence for the rest of the study, daily time-step was used for the stochastic simulation. We recommend the use of hourly simulation time-step, for the studies focussing on quantifying overflows and associated water quality implications, in absolute terms.

3.2.5. Number of Iterations for Stochastic Simulation

In stochastic simulation, input variables are specified as probability distributions. Therefore, stochastic simulation requires many runs of simulation to ensure adequate sampling from input variables, in order to produce outputs that are stable, i.e. do not vary with the number of simulation runs. Mashford *et al*. (2011) has showed that as the number simulation runs, i.e. number of iterations, increases, standard deviation of an output variable gradually reduces to a constant value, which implies that the expected value of an output variable becomes stable and more robust.

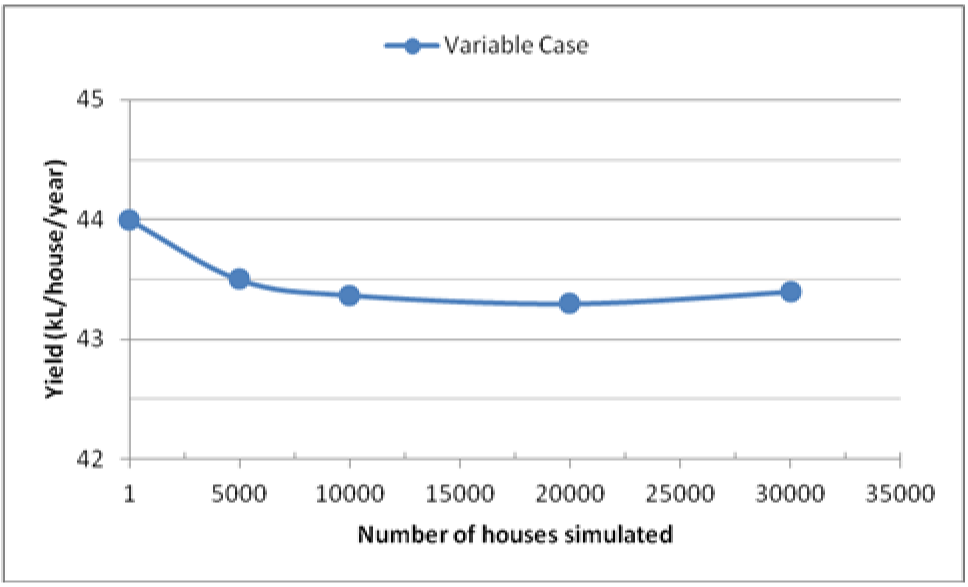


Figure 24. **Brisbane: sensitivity of tank yield to number of iterations of the stochastic simulation.**

In order to determine the number of iterations required for producing stable and robust output variables, an analysis was carried out using the data of Brisbane LGA. For this analysis, we used a daily time step for the stochastic simulation. The output variable chosen was the average annual yield over the simulation period. The value of the output variable was recorded for different number of iterations, from 1 to 30,000 as shown in Figure 24 and Table 13.

Table 13. **Brisbane: sensitivity of tank yield to number of iterations of the stochastic simulation.**

Number of iterations (or number of houses simulated)	1	100	500	5,000	10,000	20,000	30,000
Mean Tank Yield in kL/hh/yr	54.66	43.82	43.11	43.17	43.37	43.35	43.36
Standard deviation	N/A	16.11	15.67	14.65	14.74	14.67	14.70

Results shown in Figure 24 and Table 13 indicated that after 10,000 iterations, the mean tank yield value was almost the same (i.e. 43.37, 43.35 and 43.36), and the standard deviation was almost the same (i.e. 14.74, 14.67 and 14.70). This result implied that for Brisbane LGA, 10,000 iterations were adequate to ensure sufficient sampling from the probability distributions of the input variables.

The number of iterations required could vary depending on the probability distributions used for input variables. However, since the analysis was time consuming due to the computer time required to run more than 10,000 iterations, it was decided to use 10,000 iterations, for the other LGAs as well.

3.2.6. Stochastic Simulation: Results

Upon establishing the time step of simulation as a day and the number iterations required for stochastic simulation as 10,000, the next step was to determine the error introduced due to ignoring the spatial variability in tank and water use characteristics. The period of simulation was 1 January 1962 to 31 December 2011 (50 years).

To determine the error introduced due to ignoring the spatial variability in tank and water use characteristics, two cases were considered:

- **Variable case**, where the input variables of the rain water tank model were sampled from probability distributions given in Table 11 and 1,000 household water demand profiles generated from the SDG model as described in section 3.2.1; and

- **Average case**, where input variables of the rain water tank model were the average values of the 10,000 sampled values derived from the probability distributions, given in Table 15.

As described in section 3.2.4, the SDG model was calibrated for the period 1936-1985 because of the availability of hourly rainfall data for this time period. The change of simulation period to 1962-2011 to capture more recent climate for the tank simulation had meant that the SDG model had to be re-calibrated for 1962-2011, using daily maximum temperature of 1962-2011. Instead, we compared the daily maximum temperature of 1936-1985 and 1960-2009 periods to understand the differences in daily maximum temperature, with an aim of making a decision on the re-calibration of the SDG model for 1962-2011. The results of the comparison (Figure 25 and Table 14) indicated a small and an insignificant difference between the two daily maximum temperature time series. Therefore, it was concluded that the SDG model calibrated to 1936-1985 could be used for 1962-2011 period, without introducing errors to the predicted demand in 1962-2011.

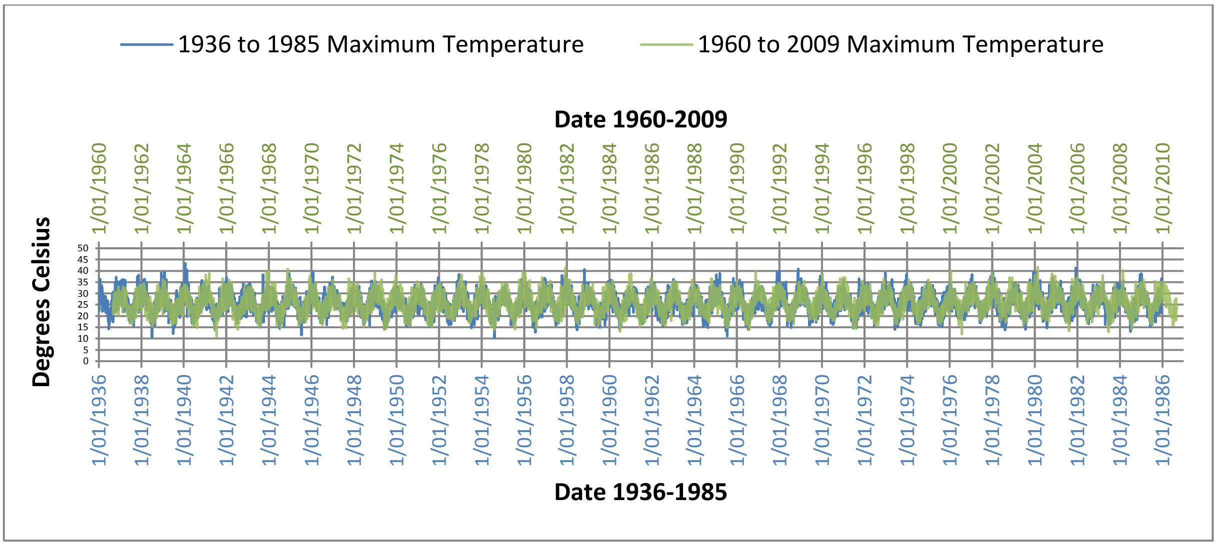


Figure 25. **Brisbane: comparison of the daily maximum temperature during 1936-1985 and 1960-2009.**

Table 14. **Brisbane: comparison of the daily maximum temperature during 1936-1985 and 1960-2009.**

T_{max} records:	1936-1985	1960-2009
Mean	25.4	25.8
Standard deviation	3.9	3.9
Min	10.2	11
Max	43.2	41.7
Count	18,263	18,262

The output variables of the simulation were: the average annual supply, the average annual overflow and the average annual TP, TN and TSS loads over the 50-year simulation period. The 10,000 iterations gave 10,000 values for the each output variable.

Table 15. **Brisbane: Average Case rainwater tank parameter values for Brisbane.**

	Tank Size	Effective Roof Area	Initial Loss	Continuing Loss
Units	**KL**	**m^2**	**mm**	**%**
Mean of 10,000 sampled values used in the variable case	5.59	115.08	0.5	14.95

3.2.6.1. Tank Yield

The 10,000 tank yield values found through stochastic simulation was plotted to understand the variability of tank yield visually (Figure 26 and Figure 27), and statistically analysed to understand the variability of tank yield quantitatively (Figure 28 and Appendix B).

The range of the variability shown by 10,000 values of tank yield was 4.6 to 116.8 kL/hh/yr. The mean was 43.37 kL/hh/yr and the standard deviation was 14.74 kL/hh/yr (Figure 26) (see Appendix B for descriptive statistics).

The average case (i.e. the case with spatial lumping effect or the case that used average values for the input variables of the rainwater tank behavioural analysis) found 50.13 kL/hh/yr as the tank supply. This is a 16 percent overestimation when compared to the mean value of the case without spatial lumping effect (i.e. 43.37 kL/hh/yr) (Figure 27).

Johnson SU was the best-fit probability distribution function to the modelled tank yields in Brisbane (Figure 28) (Kolmogorov-Smirnov statistic and P-value = 0.00606, 0.85, respectively; Chi-Squared statistic, DF and P-value = 23.189, 13, 0.04, respectively; see Appendix B for details). Since the distribution of tank yield was not symmetrical, it would be appropriate to use the 50th percentile (or median) value to report the expected tank yield in absolute terms. The 50th percentile tank yield was 42.26 kL/hh/yr.

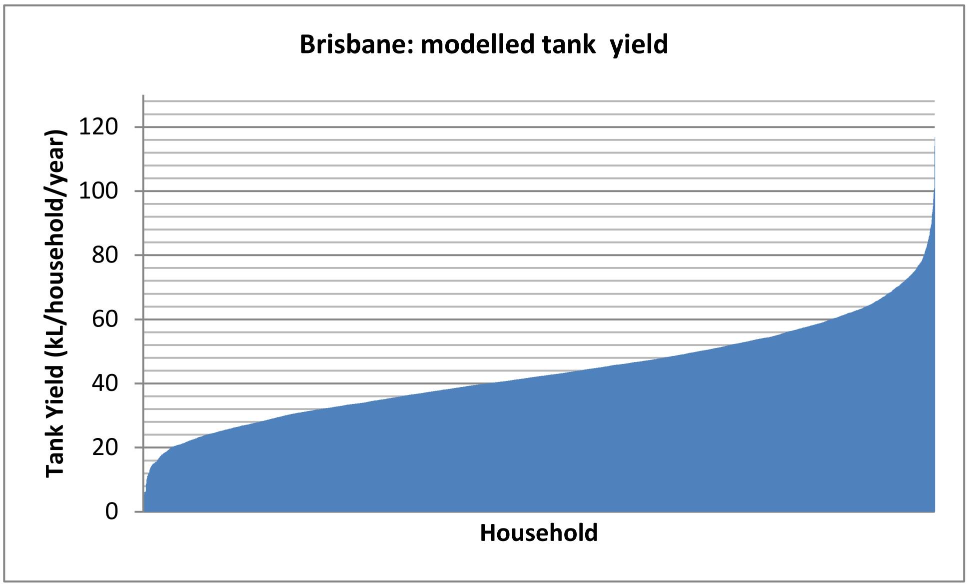


Figure 26. **Brisbane: 10,000 tank yield values, obtained from stochastic simulation.**

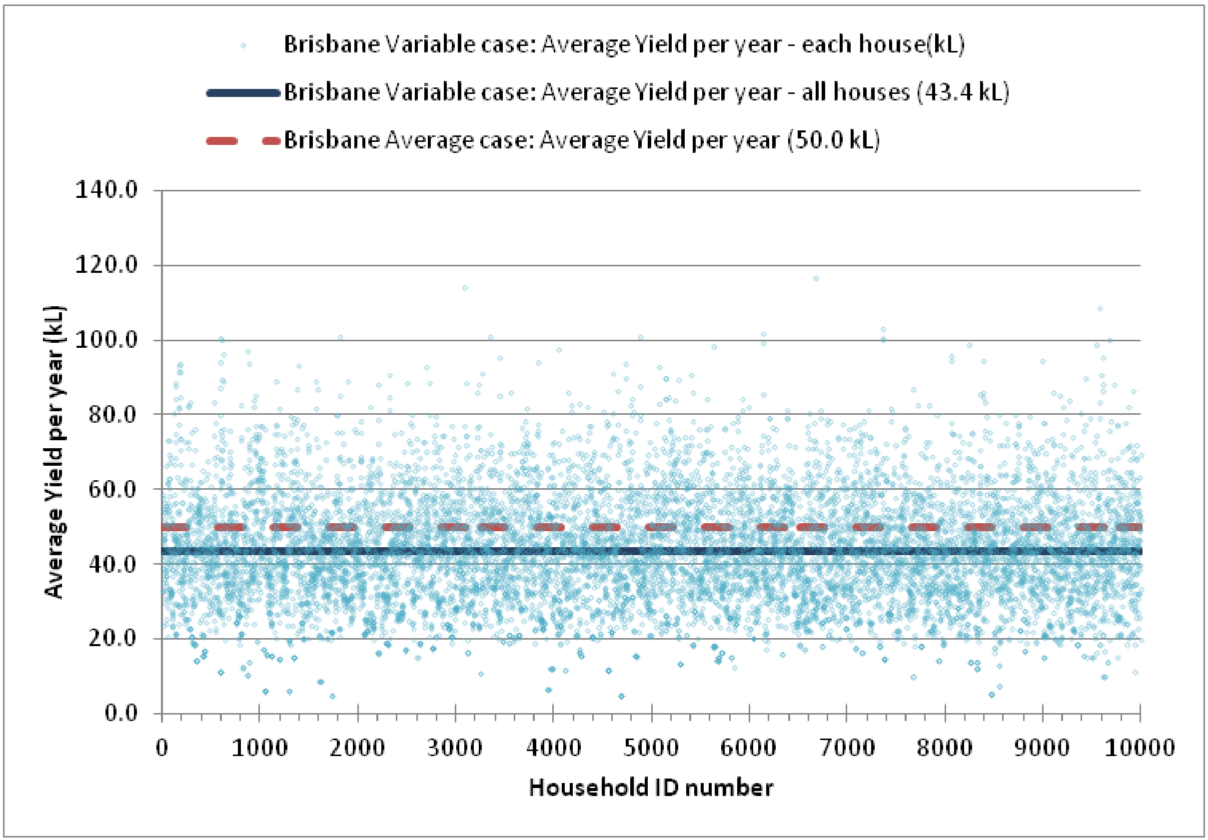
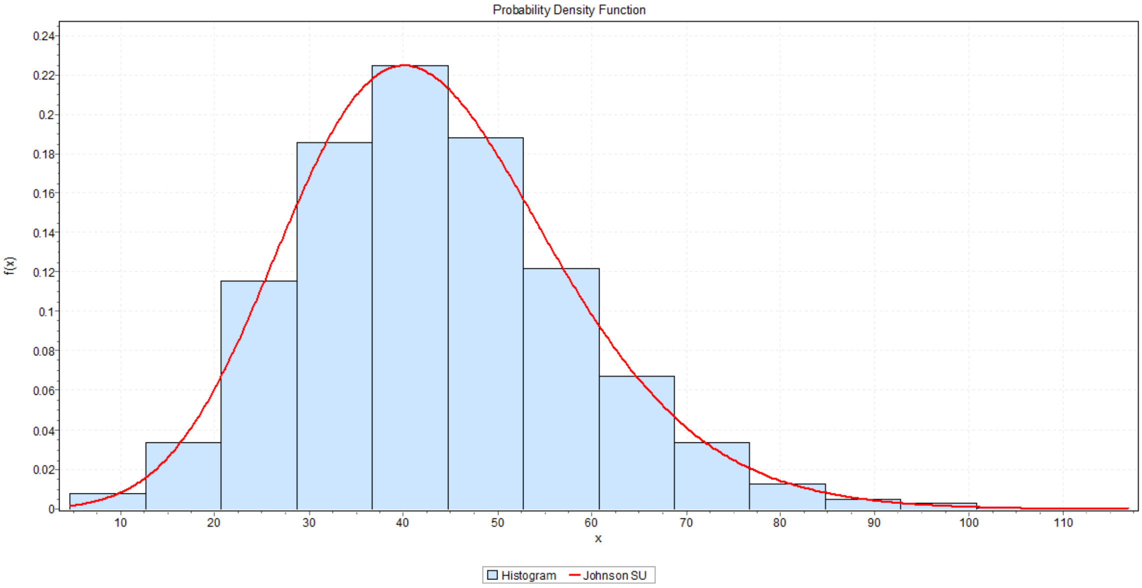


Figure 27. Brisbane: 10,000 tank yield values generated from stochastic simulation (blue dots), mean of 10,000 tank yields and the tank yield obtained by using average values of tank and water use characteristics.



Percentile	Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max
Value	4.64	21.30	25.31	33.02	42.26	52.46	62.73	69.70	116.83

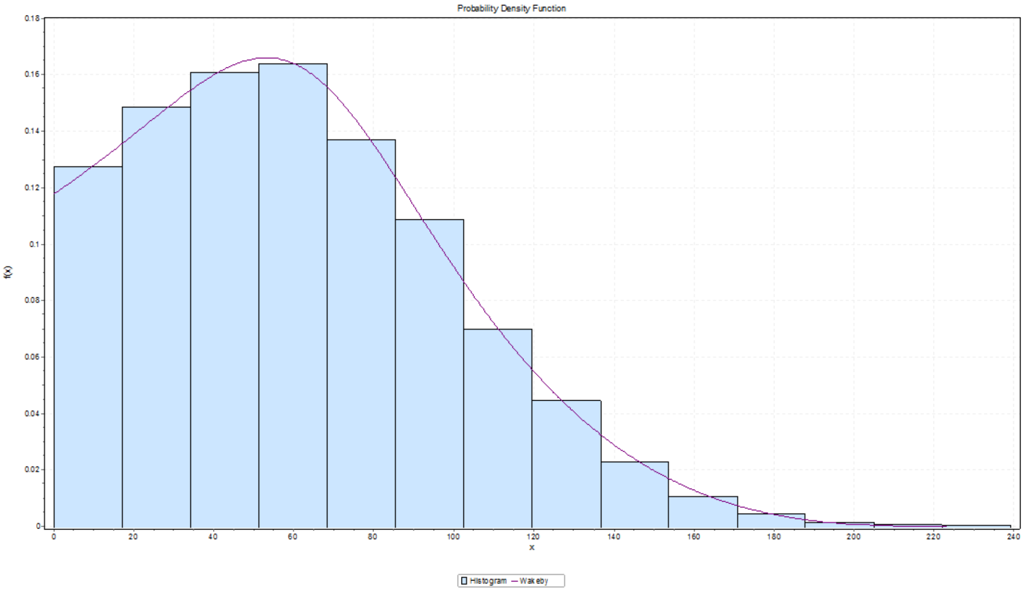
Figure 28. Brisbane: probability distribution and percentile values of tank yield (X axis represents tank yield in kL/hh/yr).

3.2.6.2. Tank Overflow

The mean of 10,000 tank overflow values was 61.78 kL/hh/yr with a standard deviation of 38.59 kL/hh/yr (see Appendix C for descriptive statistics).

The average case (i.e. the case with spatial lumping effect or the case that used average values for the input variables of the rainwater tank behavioural analysis) found 54.90 kL/hh/yr as the tank overflow. This is an 11% underestimation when compared to the mean value of the case without spatial lumping effect (i.e. 61.78 kL/hh/yr).

Wakeby distribution was the best-fit probability distribution function to the modelled tank overflows in Brisbane (Kolmogorov-Smirnov statistic and P-value = 0.00527, 0.94, respectively; see Appendix C for details). As shown in Figure 29, the distribution was not symmetrical, which indicated that 50th percentile value was appropriate to report the tank overflow in absolute terms. The 50th percentile value of the tank overflow was 57.70 kL/ household/year.



Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max	Mean	std dev
0.10	6.26	13.38	31.61	57.70	87.19	114.82	131.65	239.10	61.78	38.59

Figure 29. **Brisbane: probability distribution and percentile values of tank overflow (X axis represents tank overflow in kL/hh/yr).**

Since the stochastic simulation was carried out on a daily basis, for absolute values of overflow, the overflow value obtained with daily simulations must be corrected by considering the results reported in Table 12 (i.e. the tank overflow obtained with daily simulation was about 30% more than the tank overflow obtained with hourly simulation). If a correction was applied to account for the error caused by daily simulation, the expected tank overflow for Brisbane LGA would be 44.38 kL/hh/yr.

Table 16 shows the quality of overflow water to stormwater. The overflow load was underestimated by the average case: 17% underestimation for TSS, 22% underestimation for TP and 15% underestimation for TN. This meant that the quality of overflow water to stormwater might not be of the quality expected if an 'average' house was used to model a large cluster of houses.

However, it is important to note that TSS, TP and TN analysis was undertaken using the data obtained from literature sources due to the lack of data relevant to inflow concentrations of TP, TN, TSS. Hence, the results on TP, TN and TSS reported in this study should be treated as indicative only. It was not sensible to repeat TP, TN and TSS to other LGAs when the relevant data was not available. Hence, we did not repeat the numerical analysis to other LGAs. However the methodology described in the report could be applied when the relevant data become available in the future.

Table 16. Brisbane: TP, TN, TSS overflow water quality.

	Variable Case:			Average Case:			*Difference*		
	TSS	TP	TN	TSS	TP	TN	*TSS*	*TP*	*TN*
Overflow load, kg/hh/yr	1.027	0.630	1.101	0.856	0.489	0.931	*-17%*	*-22%*	*-15%*

In summary, for Brisbane LGA, results indicated that:

- The expected tank yield was 42.26 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation;
- The expected overflow was 44.38 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation and corrected to account for the effect of daily simulation;
- If average values were used for both tank and water use characteristics, the tank yield would be overestimated 16% and the tank overflow would be underestimated by 11%; and
- If average values were used for both tank and water use characteristics, overflow loads of TSS, TP and TN would be underestimated by 17%, 22% and 15% respectively. However, errors associated with overflow loads should be used cautiously because the results were based on the data obtained from literature, rather than from the study area.

3.2.7. Sensitivity Analysis

The sensitivity analysis was undertaken to understand the sensitivity of tank sizes, roof areas and the household water demand to tank supply and overflow. Brisbane LGA was used for this analysis. The analysis involved the use of average values all variables, except for the input variable being examined for the sensitivity. The input variable being examined for the sensitivity was specified as a probability distribution.

Results of the sensitivity analysis (Table 17) indicated that the overestimation error associated with Brisbane's tank yield is 16%, which could be reduced to 6% by considering the spatial variability of demand alone. Considering the variability in roof areas alone could reduce the overestimation of tank yield to 11% and that considering the variability in tank sizes alone can reduce the overestimation of tank yield to 14%.

Table 17. Brisbane LGA: demand, tank and roof size sensitivity analysis results.

	Average Yield per year (kL/household)	**Average Overflow per year (kL/household)**	**Difference in Yield Compared to 'All Variable Case'**	**Difference in Overflow Compared to 'All Variable Case'**
Variable Demand case	46.13	58.87	6%	-5%
Variable Tank case	49.26	55.77	14%	-10%
Variable Roof case	48.15	56.57	11%	-8%
Fully average case	50.13	54.90	16%	-11%
Fully variable case	43.37	61.78	0%	0%

Results of the sensitivity analysis (Table 17) also indicated that the underestimation error associated with Brisbane's tank overflow was 11%, which could be reduced to 5% by considering the spatial variability of demand alone. Considering the variability in roof areas alone could reduce the underestimation of tank overflow to 8% and that considering the variability in tank sizes alone can reduce the underestimation of tank overflow to 10%.

In summary, it could be said that the tank yield was highly sensitive to the demand placed on the tank. The tank overflow was highly sensitive to the demand placed on the tank, as well. These results implied the need for predicting the household end use as accurately as possible and the need for considering the spatial and temporal variability of household water use, for the accurate and robust prediction of supply and overflow from a cluster of rainwater tanks.

In addition, the connected roof area to the tank (i.e. inflow to the tank) indicated a moderate sensitivity to both tank yield and overflow, which implied the need for undertaking studies to understand the amount of inflow into the tank, which generally dependant on such factors as the area of roof connected to the tank and losses from different roof material. In general, the availability of such data was not common.

3.3. Moreton Bay

3.3.1. Probabilistic Representation of Household Demand

Household end use data were not available for Moreton Bay LGA. Hence the SDG model calibrated for Brisbane LGA (described in section 3.2.1) was used for the Moreton Bay.

3.3.2. Probabilistic Representation of Rainwater Tank Sizes

Tank sizes were sourced from Biermann *et al*. (2012). The data set had 108 houses in the Pine Rivers and Caboolture areas (Figure 30 and Figure 31).

Tanks sizes for Moreton Bay ranged from 1.22 kL to 11.89 kL, with a mean of 5.54 kL and a standard deviation of 1.59 kL (see Appendix A for descriptive statistics).

Most tank sizes were of sizes 4-6 kL (Figure 31), but their connected roof areas varied from about 25 m^2 to 250 m^2 (see Figure 30), which showed a fairly large spatial variability for the connected roof areas.

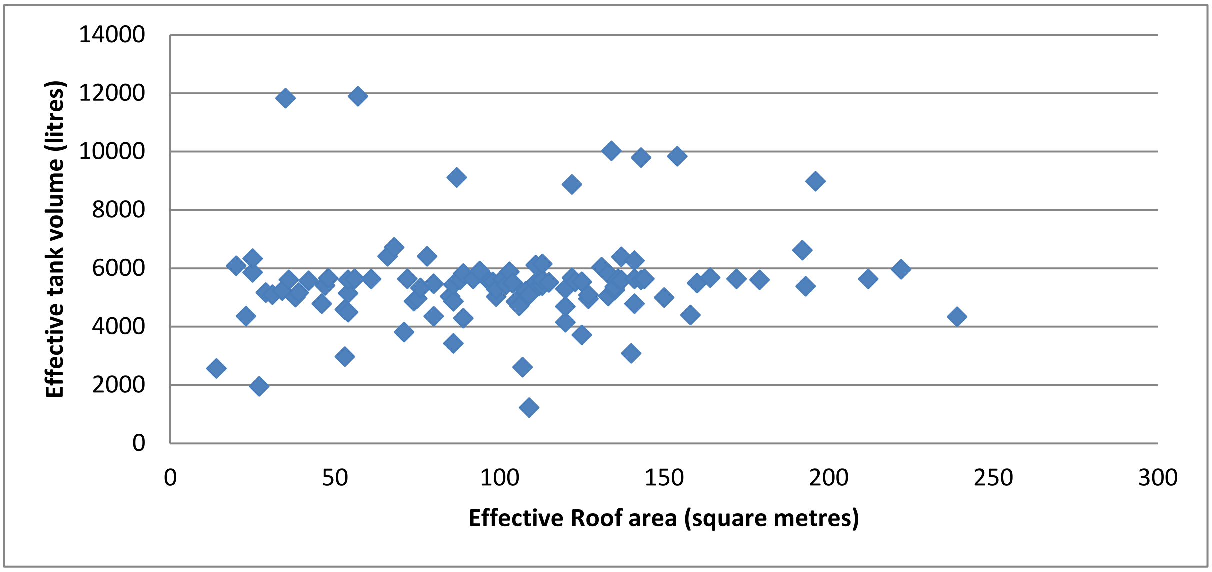


Figure 30. **Moreton Bay: Tank sizes and roof areas (sample size = 108; source Biermann *et al.*, 2012).**

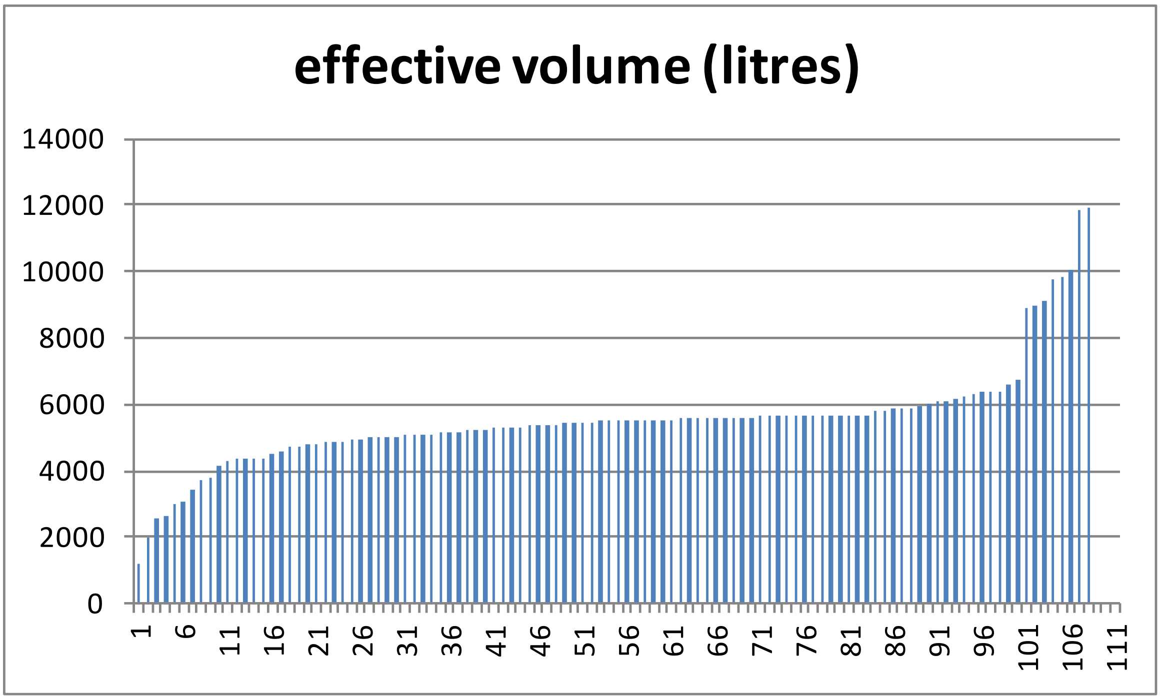


Figure 31. **Moreton Bay: Distribution of tank sizes in a sample of 108 houses for Moreton Bay.**

Similar to the Brisbane case study, the acceptability of the normal distribution was examined using Easy Fit Professional (2010), in order to understand how the observed data deviated from the normal distribution. The goodness of fit analysis indicated that the observed tank sizes were not normally distributed (Kolmogorov-Smirnov statistic and P-value = 0.2338, 0.0, respectively; Chi-Squared statistic, DF and P-value = 81.651, 5, 0.0, respectively; see Appendix A for details). Deviation of the observed data on tank sizes from the normal distribution is shown in Figure 32. The effect of this limitation was generation of a higher proportion of 6-9 kL and 3-4 kL tanks during the stochastic simulation than the observed proportion of those sizes of tanks.

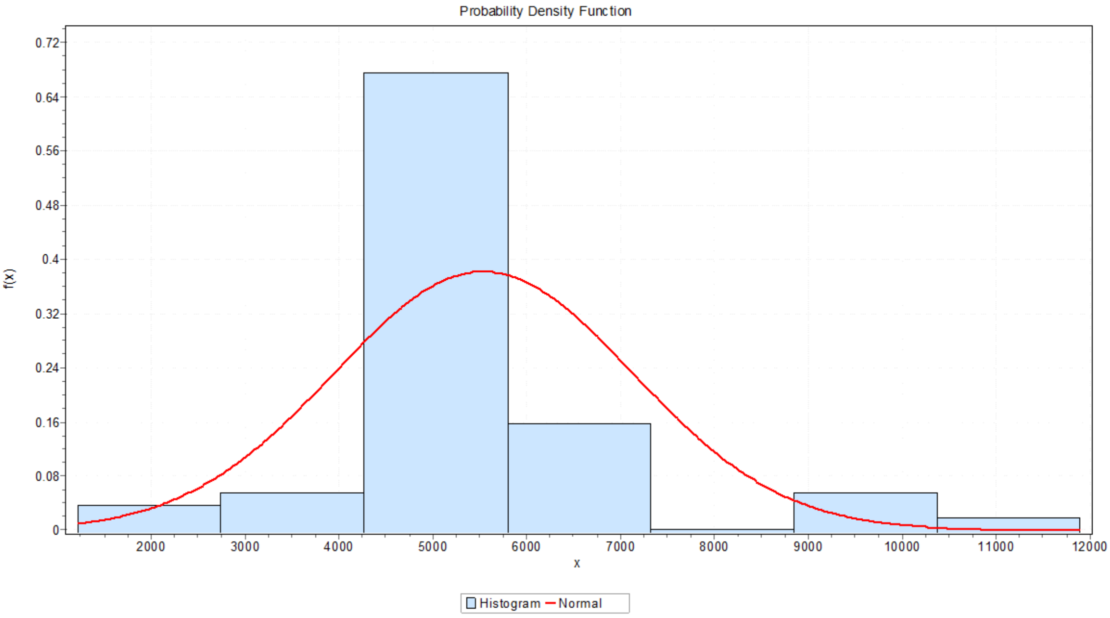


Figure 32. **Moreton Bay: Fitting tank size data to the normal distribution.**

3.3.3. Probabilistic Representation of Roof Areas

Roof sizes were sourced from Biermann *et al*. (2012). The data set had 108 houses in the Pine Rivers and Caboolture areas (Figure 33).

The roof sizes for Moreton Bay ranged from 14 m^2 to 239 m^2, with a mean of 102 m^2 and a standard deviation of 46.8 m^2 (see Appendix A for descriptive statistics).

Similar to the Brisbane case study, the acceptability of the normal distribution was examined using Easy Fit Professional (2010), in order to understand how the observed data deviated from the normal distribution. The goodness of fit analysis indicated that the observed roof areas were normally distributed (Kolmogorov-Smirnov statistic and P-value = 0.0648, 0.73, respectively; Chi-Squared statistic, DF and P-value = 6.7089, 6, 0.35, respectively; see Appendix A for details). Fitting of the observed data on roof areas to the normal distribution is shown in Figure 34.

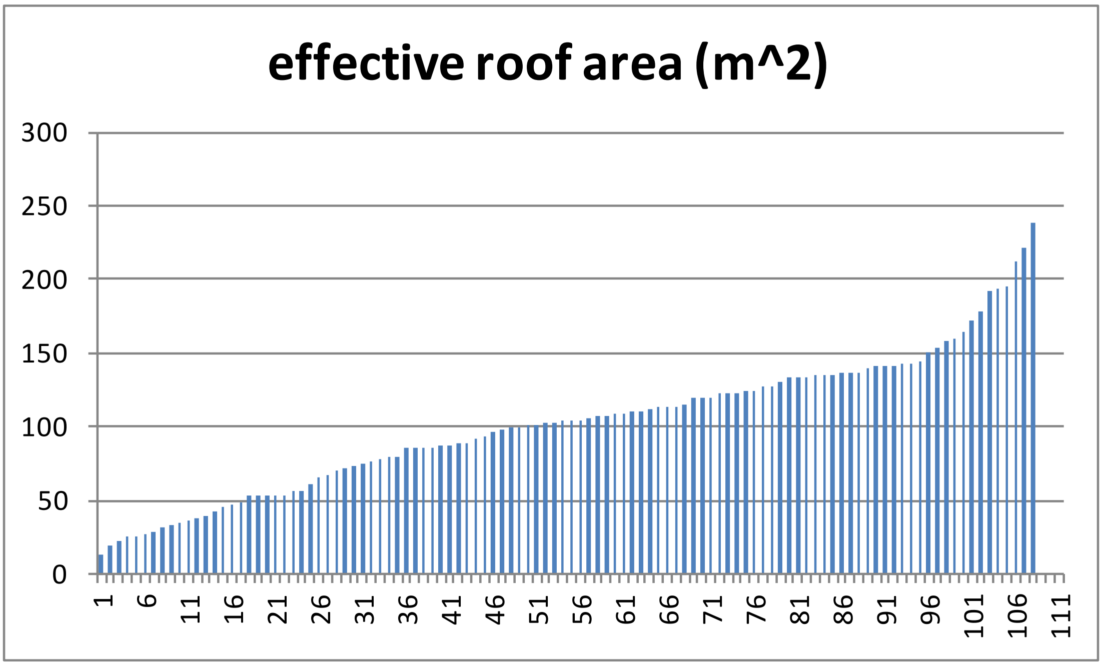


Figure 33. **Moreton Bay: Distribution of roof sizes (source: Biermann *et al.*, 2012).**

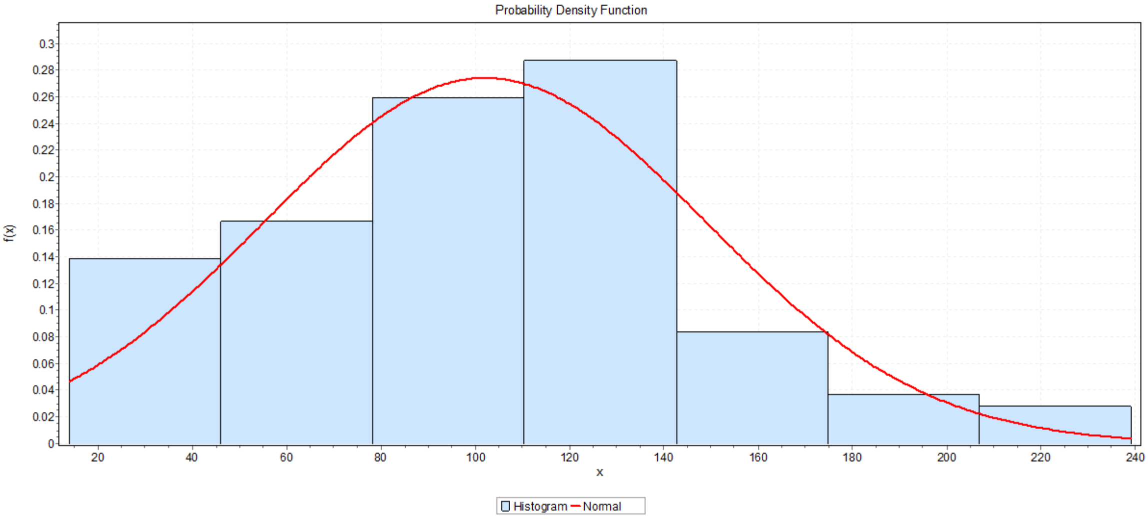


Figure 34. **Moreton Bay: Fitting roof area data to the normal distribution.**

3.3.4. Stochastic Simulation: Results

The period of simulation was 1 January 1962 to 31 December 2011 (50 years). Climate data were sourced from BOM station: 400038 Caboolture Post Office (Figure 35).

Similar to the Brisbane LGA case study, to determine the error introduced due to spatial lumping of input variables of the rainwater tank simulation, two cases were considered:

- Variable case, where the input variables of the rain water tank model were sampled from probability distributions (Table 18) and 1,000 household water demand profiles generated from the SDG model as described in section 3.2.1; and
- Average case, where input variables of the rain water tank model were the average values of the 10,000 sampled values derived from the probability distributions, given in Table 19.

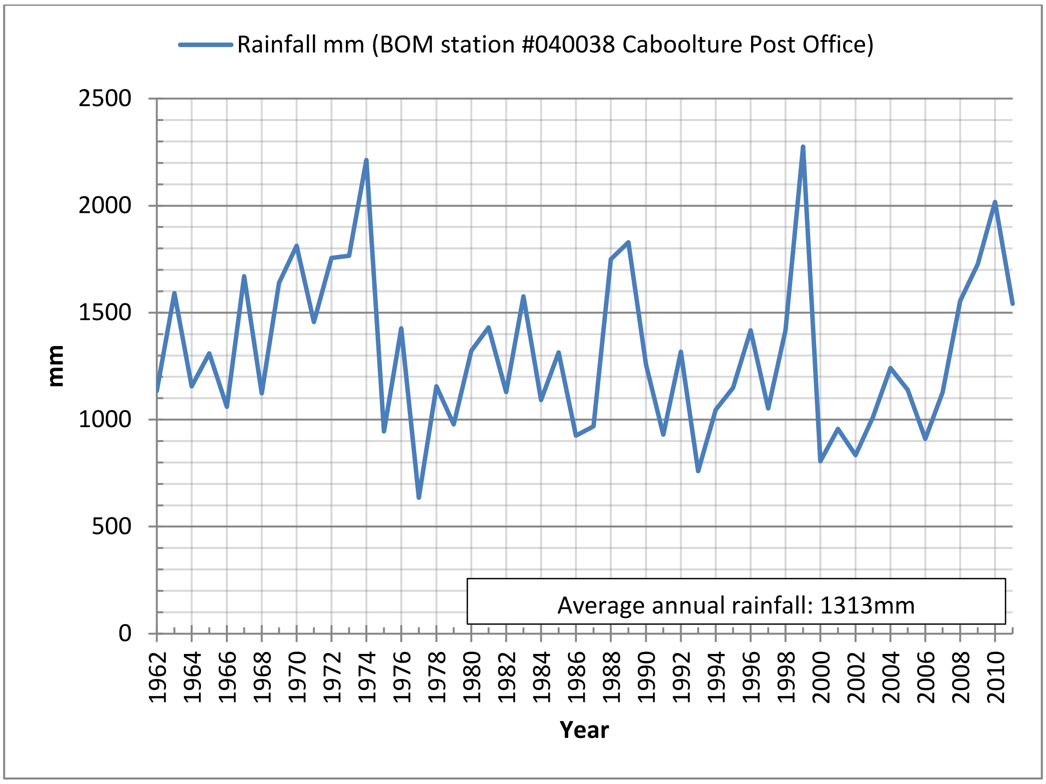


Figure 35. Moreton Bay: Annual Rainfall 1962-2011.

Table 18. Moreton Bay: input parameter values for rainwater tank simulation.

	Tank Size	Effective Roof Area	Initial Loss[(1)]	Continuing Loss[(1)]
Units	**KL**	**m^2**	**mm**	**%**
minimum	1.22	14.0	0	0
Mean	5.54	102.07	0.5	15
maximum	11.89	239.0	1.75	30
Probability distribution	Normal	Normal	Normal	Normal
Standard Deviation	1.59	46.8	0.5	5
Sample size	1082	1083	0(1)	0(1)

Note #1: data not available for SEQ. Used Melbourne-based data reported in Xu *et al*. (2010).

Table 19. **Moreton Bay: Average Case rainwater tank parameter values.**

	Tank Size	Effective Roof Area	Initial Loss	Continuing Loss
Units	**kL**	**m^2**	**mm**	**%**
Mean of 10,000 sampled values used in the variable case	5.54	105.06	0.64	14.94

Similar to the Brisbane application, the storage behaviour of a rainwater tank was examined for 10,000 iterations, on a daily basis over a 50-year simulation period. The 10,000 iterations gave 10,000 values for the each output variable, i.e. a daily tank supply time series and a daily overflow time series over 50 years. The daily values were aggregated, plotted and analysed statistically.

3.3.4.1. Tank Yield

The 10,000 tank yield values found through stochastic simulation was plotted to understand the variability of tank yield visually (Figure 36 and Figure 37), and statistically analysed to understand the variability of tank yield quantitatively (Figure 38 and Appendix B).

The range of the variability shown by 10,000 values of tank yield was 4.6 to 125.4 kL/hh/yr (Figure 36). The mean was 43.90 kL/hh/yr and the standard deviation was 15.67 kL/hh/yr (see Appendix B for descriptive statistics).

The average case (i.e. the case with spatial lumping effect or the case that used average values for the input variables of the rainwater tank behavioural analysis) found 50.32 kL/hh/yr as the tank supply (Figure 37). This is a 15 percent overestimation when compared to the mean value of the case without spatial lumping effect (i.e. 43.90 kL/hh/yr).

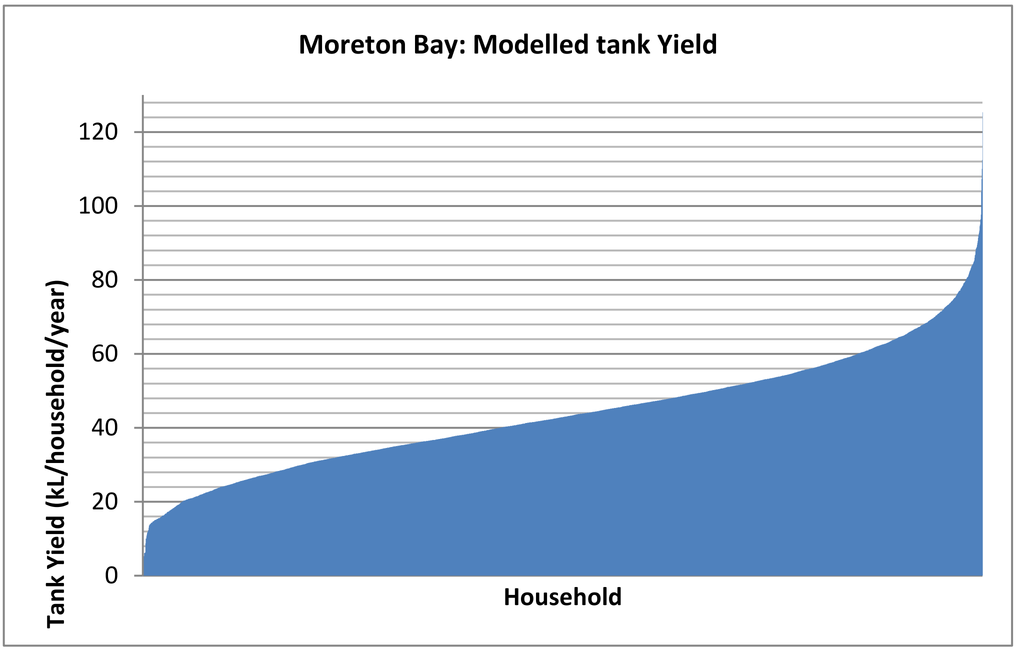


Figure 36. **Moreton Bay: 10,000 tank yield values, obtained from stochastic simulation.**

Burr (4P) was the best-fit probability distribution function to the modelled tank yields in Moreton Bay (Kolmogorov-Smirnov statistic and P-value = 0.00647, 0.79, respectively; Chi-Squared statistic, DF and P-value = 19.369, 13, 0.11, respectively; see Appendix B for details). The 50th percentile tank yield was 42.92 kL/hh/yr. Since the distribution of tank yield was not symmetrical, the median value was used to report the expected tank yield for Moreton Bay in absolute terms.

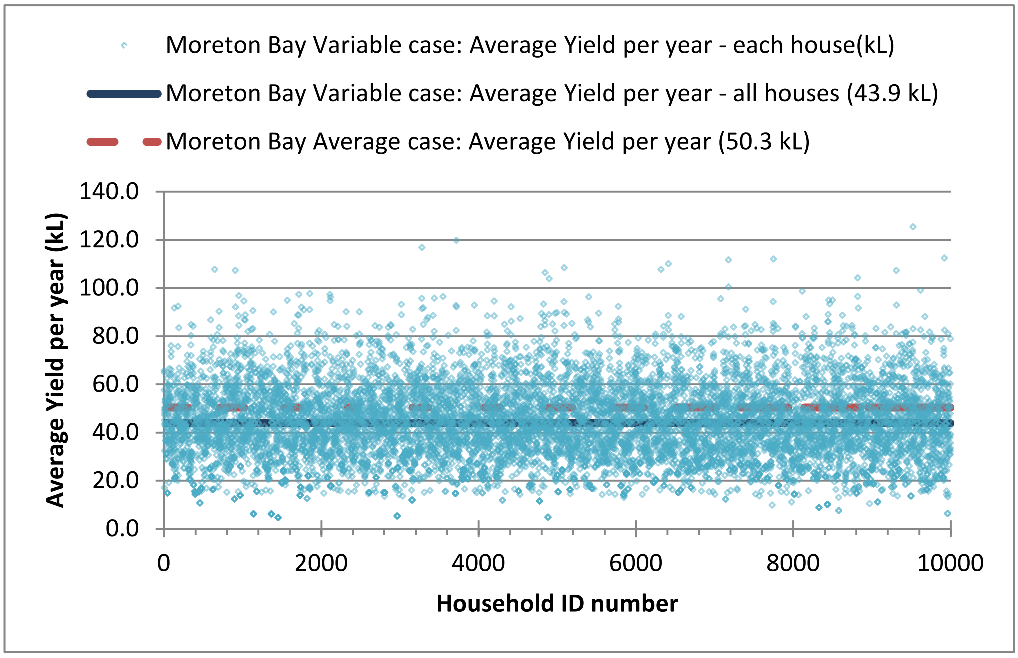
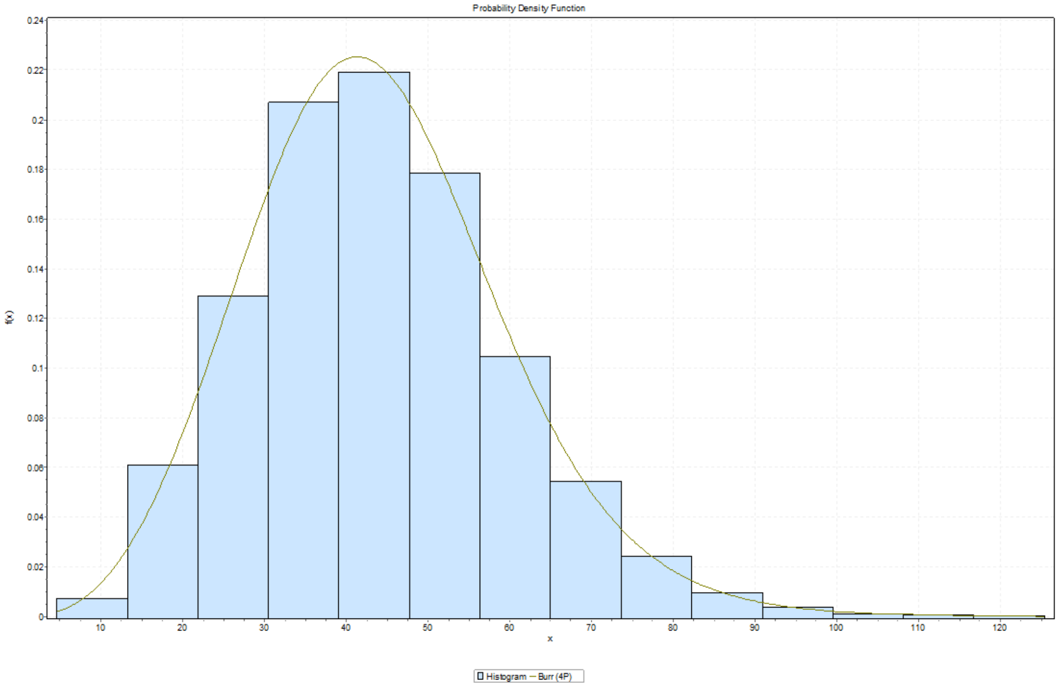


Figure 37. **Moreton Bay: 10,000 tank yield values generated from stochastic simulation (blue dots), mean of 10,000 tank yields and the tank yield obtained by using average values of tank and water use characteristics.**



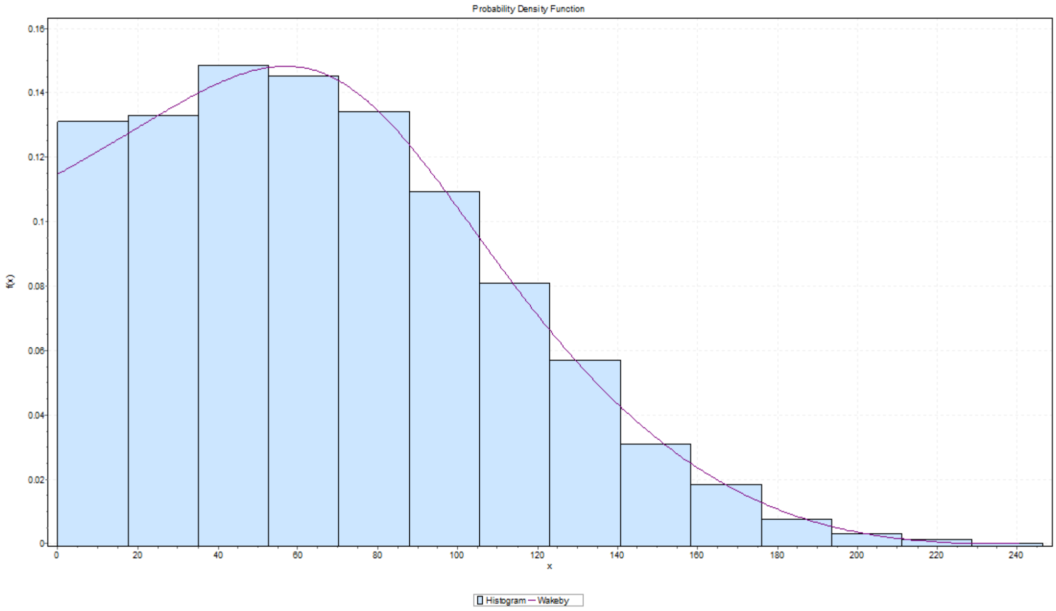
Percentile	Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max
Value	4.6393	20.393	24.433	32.858	42.916	53.5	64.518	71.452	125.36

Figure 38. **Moreton Bay: probability distribution and percentile values of tank yield (X axis represents tank yield in kL/hh/yr).**

3.3.4.2. Tank Overflow

The mean of 10,000 tank overflow values was 67.86 kL/hh/yr with a standard deviation of 43.47 kL/hh/yr (see Appendix C for descriptive statistics).

The average case (i.e. the case with spatial lumping effect or the case that used average values for the input variables of the rainwater tank behavioural analysis) found 61.32 kL/hh/yr as the tank overflow. This is a 10% underestimation when compared to the mean value of the case without spatial lumping effect (i.e. 67.86 kL/hh/yr).



Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max	Mean	std dev
0.00	5.47	13.14	33.60	63.55	97.37	128.63	145.77	246.22	67.86	43.47

Figure 39. **Moreton Bay: probability distribution and percentile values of tank overflow (X axis represents tank overflow in kL/hh/yr).**

The 10,000 tank overflow values in kL/hh/yr were fitted to a set of theoretical distribution functions using Easy Fit Professional (2010). Wakeby distribution was the best-fit probability distribution function to the modelled overflow in Moreton Bay (Kolmogorov-Smirnov statistic and P-value = 0.01051, 0.22, respectively; see Appendix C for details). As shown in Figure 39, the distribution was not symmetrical, which indicated that 50th percentile value was appropriate to report the tank overflow in absolute terms. The 50th percentile value of the tank overflow was 63.55 kL/hh/yr.

Since the stochastic simulation was carried out on a daily basis, for absolute values of overflow, the overflow value obtained with daily simulations must be corrected by considering the results reported in Table 12 (i.e. the tank overflow obtained with daily simulation was about 30% more than the tank overflow obtained with hourly simulation). If a correction was applied to account for the error caused by daily simulation, the expected tank overflow for Moreton Bay LGA would be 48.88 kL/hh/yr.

In summary, for Moreton Bay LGA, results indicated that:

- The expected tank yield was 42.92 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation;
- The expected overflow was 48.88 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation and corrected to account for the effect of daily simulation; and
- If average values were used for both tank and water use characteristics, the tank yield would be overestimated 15% and the tank overflow would be underestimated by 10%.

3.3.5. Demonstration on How to Inform Local Government TWCM Plan Development

The TWCM plan development for Moreton Bay LGA was undertaken (BMT WBM, 2012) in parallel to the study. Hence, outputs of the study were not available at the time of undertaking the Moreton Bay TWCM plan. In this section, we demonstrate how the study outputs could have been used to inform the Moreton Bay TWCM plan.

The Moreton Bay TWCM Plan specified the way in which future water management should be provided for the Moreton Bay LGA. To develop the plan, the LGA was divided into 11 catchments (Figure 40), considered three scenarios of water management for each catchment, evaluated the scenarios in terms of a range of criteria in line with the triple bottom objectives and recommended a preferred scenario of water management for each catchment. A scenario was a set of water management options, e.g. scenario 1 consisted of rainwater tanks for all new residential developments and measures to achieve stormwater quality targets. All three scenarios considered domestic rainwater tanks. Two of the criteria used for the evaluation of scenarios were: the amount of potable water savings (i.e. in rainwater tank context, the tank yield) and the TP, TN and TSS load reduction to the Moreton Bay.

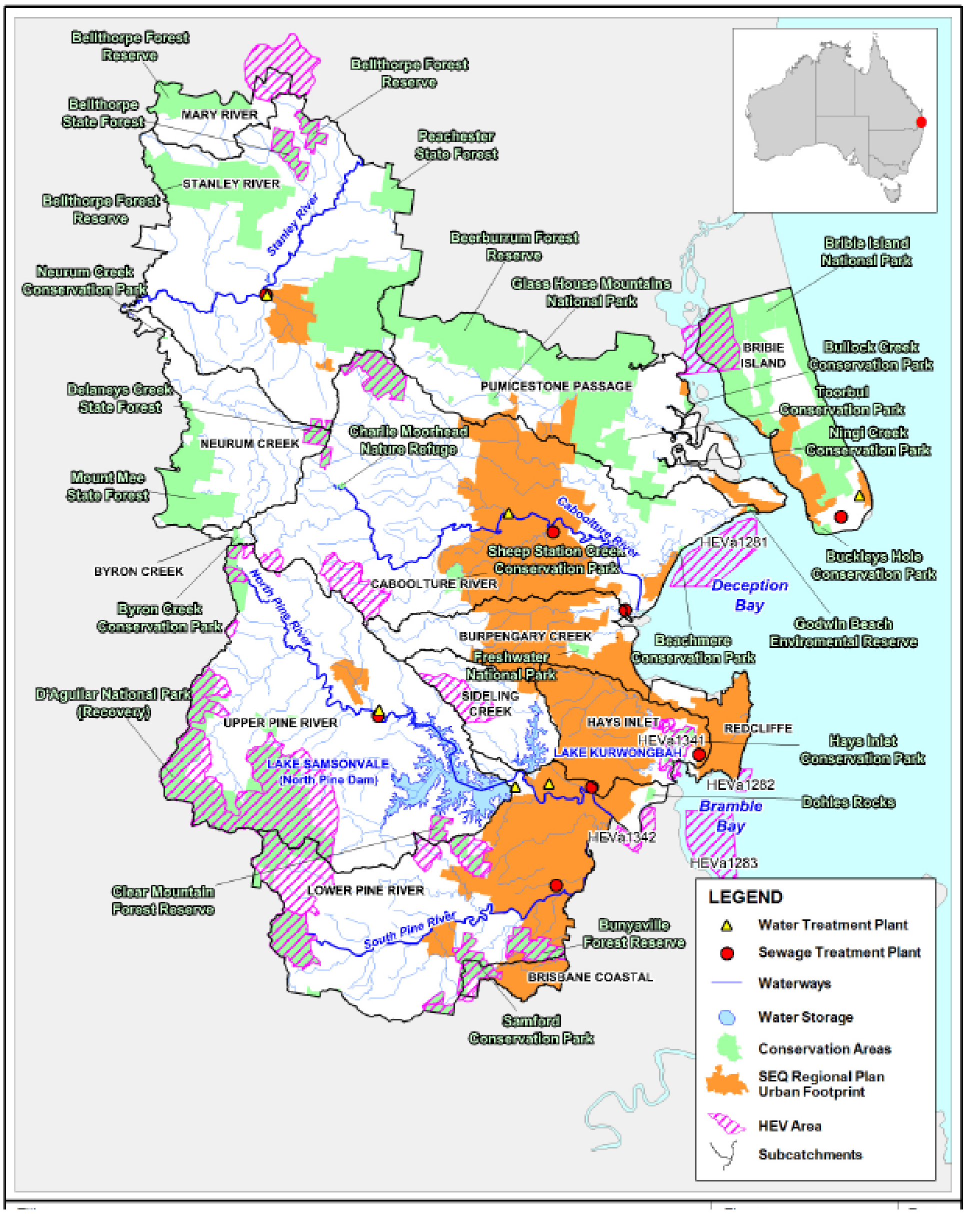


Figure 40. **Moreton Bay: key catchments considered in the TWCM Plan (source: BMT WBM, 2012).**

The following average values were used in the Moreton Bay TWCM Plan (BMT WBM, 2012), in regard to rainwater tanks:

- Household occupancy of 2.8 people per household
- Toilet and laundry use of 54.7 L/p/d
- Outdoor use of 25 L/p/d
- Rainwater tank supplied 70% of toilet, laundry and garden use. That is, the tank yield was 55.79 L/p/d (i.e. 70% of 79.7 L/p/d).

If the outcomes of our study were to be used to inform the development of the Moreton Bay TWCM Plan, the amount of potable water saved from the rainwater tanks would be: 42.92 kL/hh/yr or 41.97 l/p/d (assuming 365.25 days per year and the same occupancy rate of 2.8 persons per household). Therefore, it can be said that the tank yield figure used in the current TWCM plan in Moreton Bay was 33% more than the tank yield figure found from our study.

In regard to TP, TN and TSS loads, the TWCM plan required quantification of the reduction in loads due to the presence of rainwater tanks. Outcomes of our study indicated that TP, TN and TSS loads associated with the tank overflow would be underestimated (i.e. the reduction in TP, TN and TSS loads to would be overestimated), if average tank and demand characteristics were used. Based on the data sourced from the literature, the study indicated 17%, 22% and 15% underestimation for TSS, TP and TN respectively. Therefore, if the Moreton Bay TWCM plan used average tank and water use characteristics for the quantification of potential water quantity and quality implications of rainwater tanks, it is recommended that the estimated reduction in TSS, TP and TN loads to waterways/coastal waters should be reduced by 17%, 22% and 15%, respectively, to account for the spatial variability expected in tank sizes, roof areas, inflow concentrations of TSS, TP and TN into the tank and the demand.

3.4. Sunshine Coast

3.4.1. Probabilistic Representation of Household Demand

3.4.1.1. Calibration of the Stochastic Demand Model: Input Data

To calibrate the modified SDG model described in Chapter 2, household end use water demand data were sourced from Beal and Stewart’s (2011) residential end use measurement study. It provided end use water consumption statistics for 67 single family residential (SFR) households in Gold Coast. Due to the reasons explained in the Brisbane LGA case study, we used 2010 winter data set for this study.

The end use water consumption statistics used to calibrate the modified SDG model to Sunshine Coast LGA were event mean volume for toilet, tap, dishwasher and clothes washer end uses in litres/event (Table 20), frequency of event for toilet, tap, shower, bath, dishwasher, clothes washer and garden water use (i.e. irrigation) end uses in events/day (Table 21), shower flow rate in litres/minute (Table 7) and shower duration in minutes (Table 8).

Table 20. **Sunshine Coast: end use event mean volume statistics (data source: Beal and Stewart, 2011).**

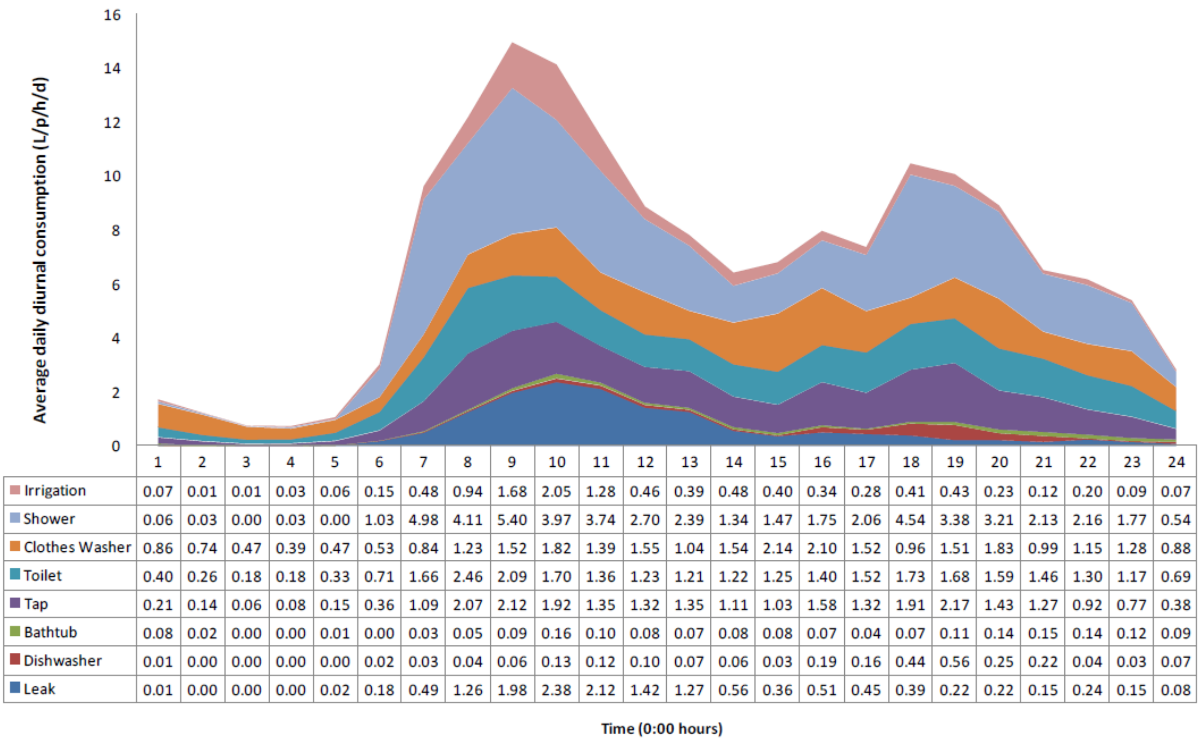
Sunshine Coast Statistics	Mean Volume of End Use Event (Litres/Event)				
	Half Flush	Full Flush	Tap	Dishwasher	Clothes Washer
Mean	4.08	7.90	1.14	6.88	101.17
Standard Deviation	0.94	1.66	0.39	7.16	64.38
Skewness	-0.78	0.97	2.41	0.62	1.04

Table 21. **Sunshine Coast: end use frequency statistics (Beal and Stewart, 2011).**

Sunshine Coast Statistics	Frequency (Events Per Day)							
	Half Flush	Full Flush	Tap	Shower	Bath	Dishwasher	Clothes Washer	Irrigation
Mean	6.51	4.76	49.33	1.82	0.05	0.58	0.72	0.07
Standard Deviation	4.05	2.92	21.27	1.02	0.17	0.83	0.57	0.11
Skewness	0.50	1.08	0.16	0.74	3.65	2.59	2.78	1.10

The diurnal pattern of each end use was used to generate probabilities for triggering events for each end use (Figure 41). The probability distributions used for each end use (found through calibration) is shown in Table 9.

The time period of simulation was 1 January 1962 to 31 December 2011 (50 years). Calibration of the modified SDG model involved generating a sufficient number of demand time series (or profiles) and compare modelled statistics of each end use with the corresponding observed values. For this analysis, we generated 1,000 demand profiles.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Irrigation	0.07	0.01	0.01	0.03	0.06	0.15	0.48	0.94	1.68	2.05	1.28	0.46	0.39	0.48	0.40	0.34	0.28	0.41	0.43	0.23	0.12	0.20	0.09	0.07
Shower	0.06	0.03	0.00	0.03	0.00	1.03	4.98	4.11	5.40	3.97	3.74	2.70	2.39	1.34	1.47	1.75	2.06	4.54	3.38	3.21	2.13	2.16	1.77	0.54
Clothes Washer	0.86	0.74	0.47	0.39	0.47	0.53	0.84	1.23	1.52	1.82	1.39	1.55	1.04	1.54	2.14	2.10	1.52	0.96	1.51	1.83	0.99	1.15	1.28	0.88
Toilet	0.40	0.26	0.18	0.18	0.33	0.71	1.66	2.46	2.09	1.70	1.36	1.23	1.21	1.22	1.25	1.40	1.52	1.73	1.68	1.59	1.46	1.30	1.17	0.69
Tap	0.21	0.14	0.06	0.08	0.15	0.36	1.09	2.07	2.12	1.92	1.35	1.32	1.35	1.11	1.03	1.58	1.32	1.91	2.17	1.43	1.27	0.92	0.77	0.38
Bathtub	0.08	0.02	0.00	0.00	0.01	0.00	0.03	0.05	0.09	0.16	0.10	0.08	0.07	0.08	0.08	0.07	0.04	0.07	0.11	0.14	0.15	0.14	0.12	0.09
Dishwasher	0.01	0.00	0.00	0.00	0.00	0.02	0.03	0.04	0.06	0.13	0.12	0.10	0.07	0.06	0.03	0.19	0.16	0.44	0.56	0.25	0.22	0.04	0.03	0.07
Leak	0.01	0.00	0.00	0.00	0.02	0.18	0.49	1.26	1.98	2.38	2.12	1.42	1.27	0.56	0.36	0.51	0.45	0.39	0.22	0.22	0.15	0.24	0.15	0.08

Figure 41. **Sunshine Coast: average daily diurnal pattern (data source: Beal and Stewart, 2011).**

3.4.1.2. Calibration of the Stochastic Demand Model: Results

The observed and the modelled demand of each end use were compared in terms of mean, standard deviation, minimum value and maximum value, of each end use in litres/person/day (Table 22), total water use and end use breakdown (Figure 42) and the distribution of each end use and the total water use (Figure 43).

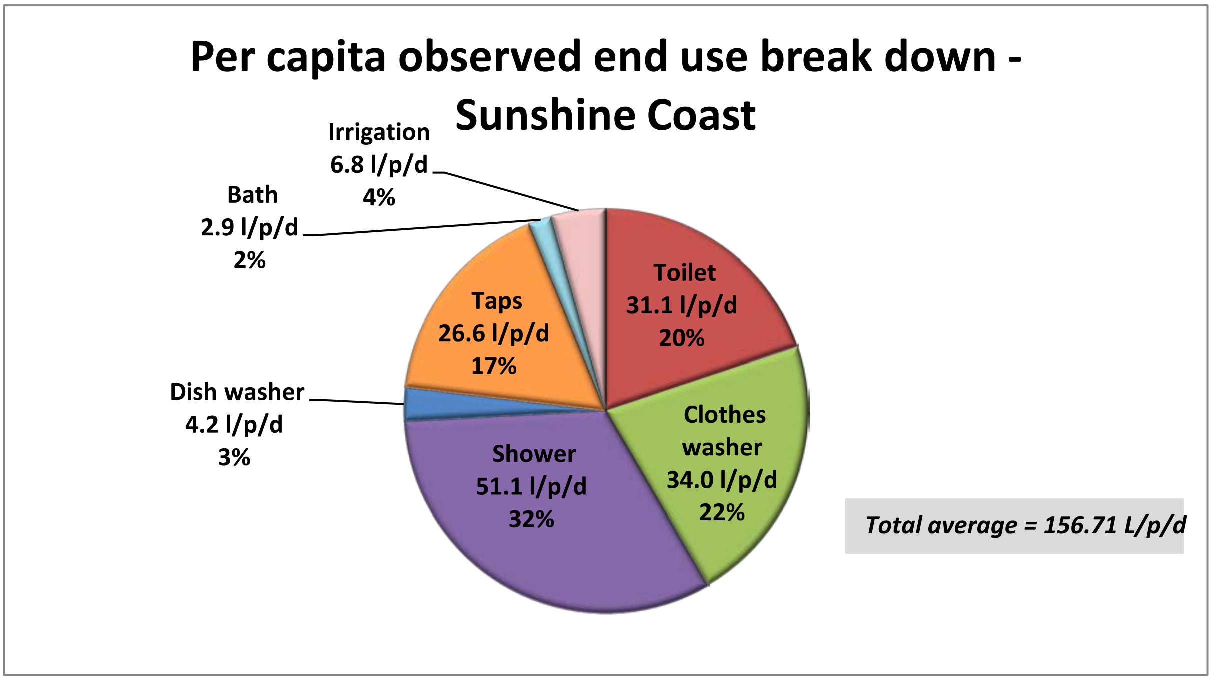
During the calibration, we paid attention to toilet, clothes washer and irrigation end uses (i.e. to obtain the modelled distribution of these end uses match with the observed distributions as closely as possible) because they were the end uses being supplemented with rainwater as per Queensland Development Code 3.2. The distributions of toilet, clothes washer and irrigation demands are shown (i.e. Figure 43).

Table 22. **Sunshine Coast: observed and modelled household end use demands.**

	Household End Use Water Demand in Litres/Person/Day							
	Toilet	Clothes Washer	Shower	Dishwasher	Tap	Bathtub	Irrigation	Total
Observed Mean	31.10	34.00	51.10	4.20	26.60	2.90	6.80	156.70
Modelled Mean	29.80	34.57	52.31	3.37	25.66	3.14	6.55	155.41
Observed Standard Deviation	21.36	32.25	44.48	8.04	17.74	12.45	17.84	103.88
Modelled Standard Deviation	12.68	40.04	57.18	4.89	7.17	0.03	6.56	72.69
Observed Min	8.79	4.25	2.92	0.00	3.98	0.00	0.00	38.46
Modelled Min	29.80	34.57	52.31	3.37	25.66	3.14	6.55	155.41
Observed Max	148.7	192.6	250.8	47.2	83.7	76.6	98.2	590.9
Modelled Max	109.25	375.72	540.27	40.28	61.13	3.24	30.66	1,412.38

As indicated by these results the average household consumption during the measured period (i.e. 14-28 June 2010) without considering leaks was 156.7 L/p/d. The simulated or modelled value of household consumption was 155.4 L/p/d. Comparison of the observed and modelled end use breakdown indicated that modelled demands were of similar order of magnitude to the observed demands.

Upon calibrating the SDG model, 1,000 probable demand time series of 50 years were generated for each end use, in one minute time scale. These were then aggregated to match with the time step of simulation of rainwater tank simulation and used as probable values for the input variable on ‘demand’ in the rainwater tank model. This was to undertake tank yield, overflow and water quality analysis in line with the study objectives stated in Chapter 1.



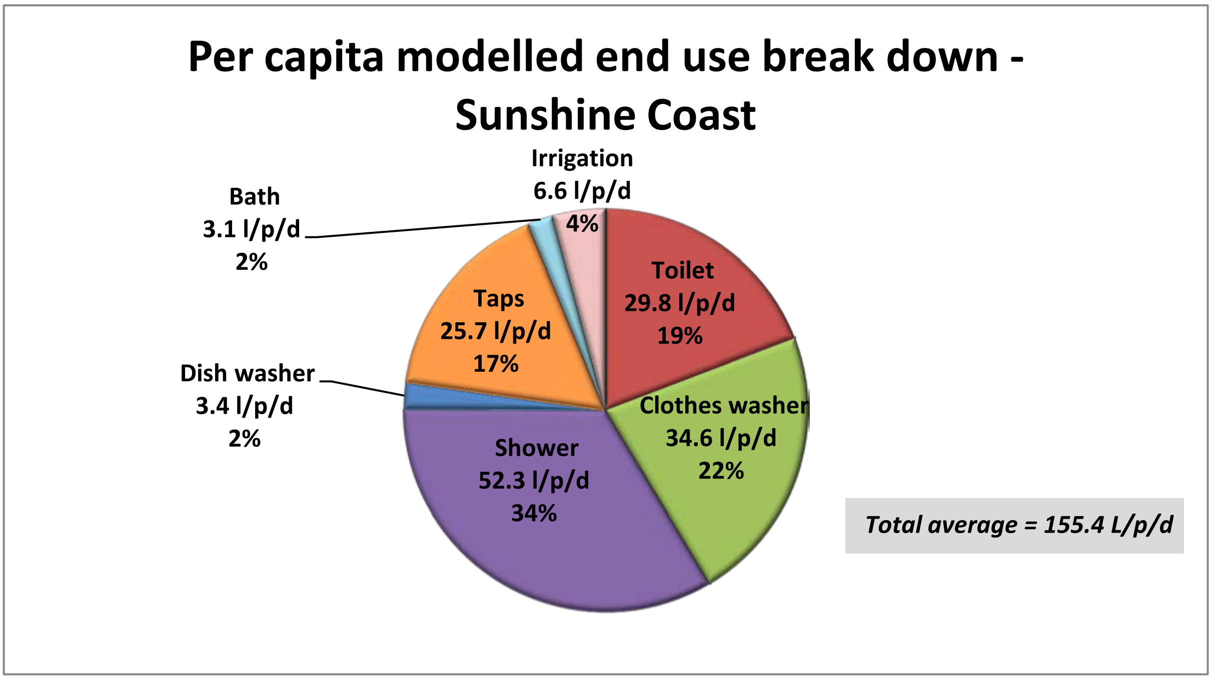


Figure 42. **Sunshine Coast: comparison of observed (top) and modelled (bottom) total water use and per capita end use breakdown.**

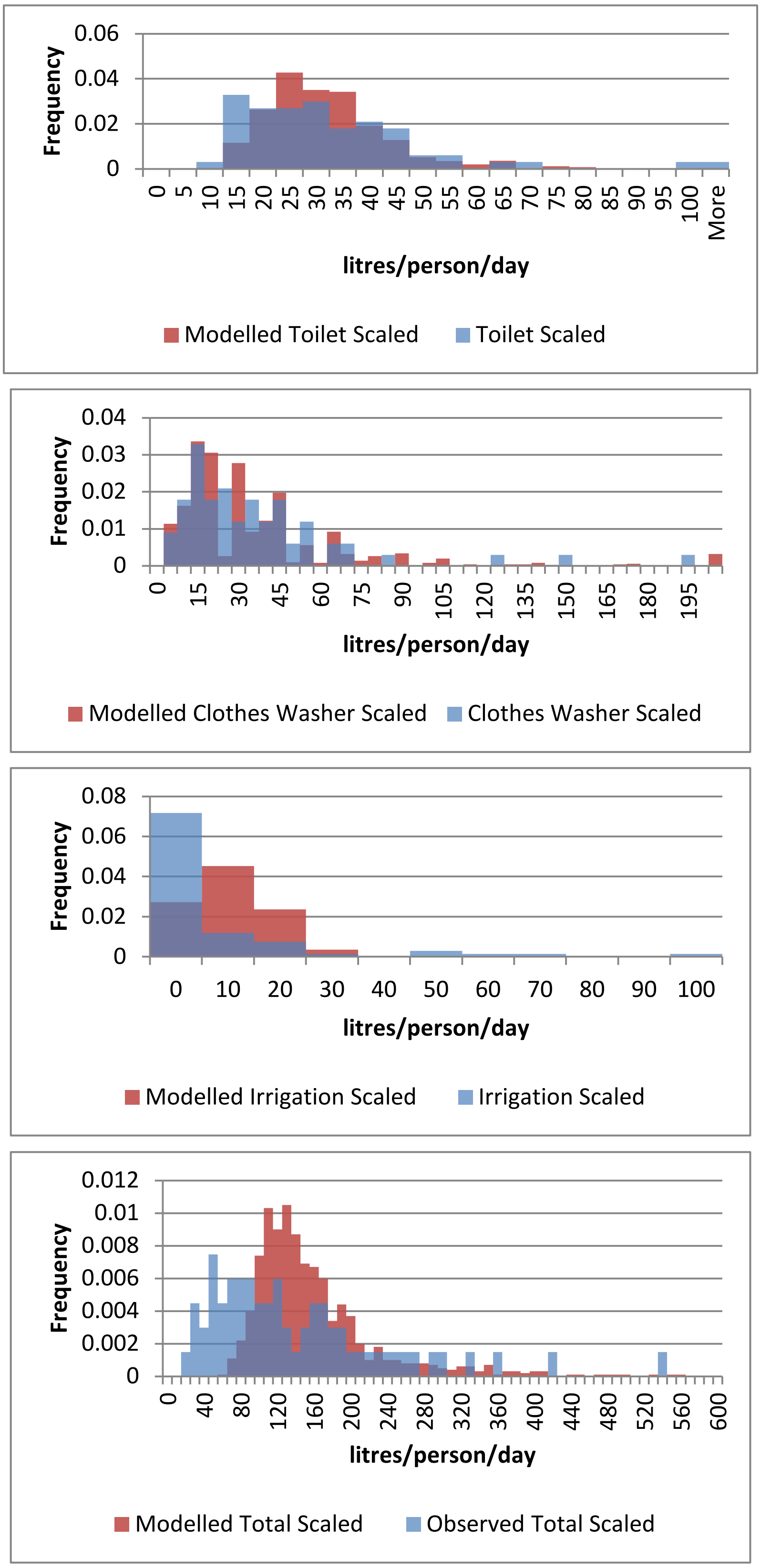


Figure 43. **Sunshine Coast: comparison of frequency distributions of observed and modelled toilet, laundry, irrigation and total per capita water use.**

3.4.2. Probabilistic Representation of Rainwater Tank Sizes

Tank sizes were sourced from the Home and garden Waterwise Rebate Scheme (HWRS), provided by the QWC. The data sample contained 438 tanks and their nominal sizes. The relationship described under Brisbane LGA case study was used to convert nominal tank sizes to effective tank sizes. The effective sizes of tanks in this sample ranged from 2.66 kL to 29.31 kL, with a mean of 5.63 kL and a standard deviation of 4.596 kL (Figure 44 and Appendix A).

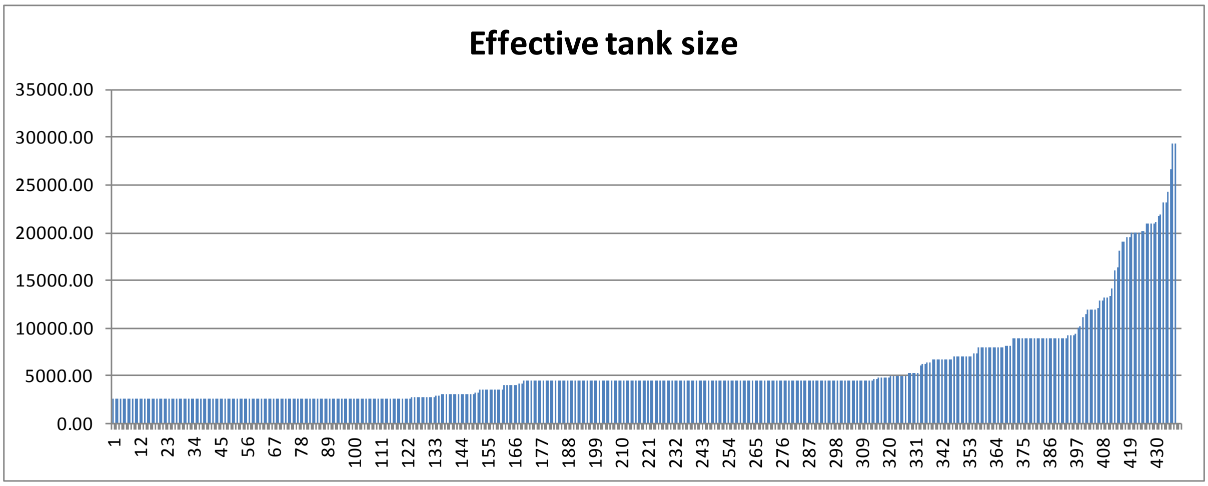


Figure 44. **Sunshine Coast: tank sizes.**

Similar to Brisbane case study, the acceptability of the normal distribution was examined using Easy Fit Professional (2010), in order to understand how the observed data deviated from the normal distribution.

The goodness of fit analysis indicated that the observed tank sizes were not normally distributed (Kolmogorov-Smirnov statistic and P-value = 0.30912, 0, respectively; Chi-Squared statistic, DF and P-value = 469.61, 8, 0, respectively; see Appendix A for details). Deviation of the observed data on tank sizes from the normal distribution is shown in Figure 45. The effect of this limitation was generation of a lower proportion of 4-5 kL tanks and a higher proportion of 6-14 kL tanks than the proportions observed for those tank sizes in the observed sample.

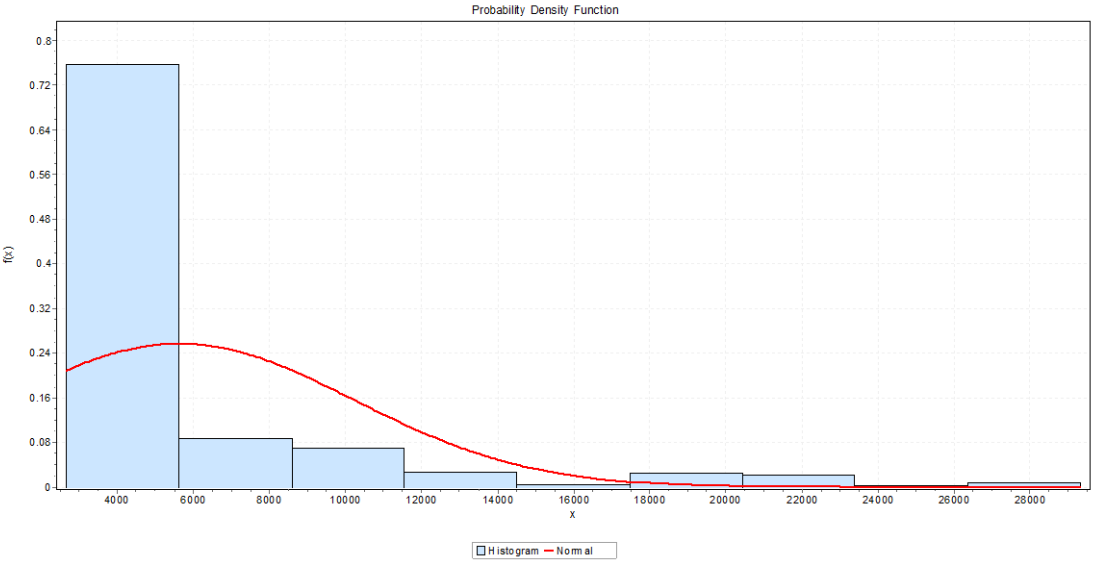


Figure 45. **Sunshine Coast: fitting tank size data to the normal distribution (x axis represents tank sizes in litres).**

3.4.3. Probabilistic Representation of Roof Areas

Roof areas are not available. We used Caboolture and Pine Rivers (i.e. Moreton Bay) sample of 108 houses sourced from Biermann *et al.* (2012).

3.4.4. Stochastic Simulation

The period of simulation was 1 January 1962 to 31 December 2011 (50 years). Climate data were sourced from BOM station: 40078 (Figure 46).

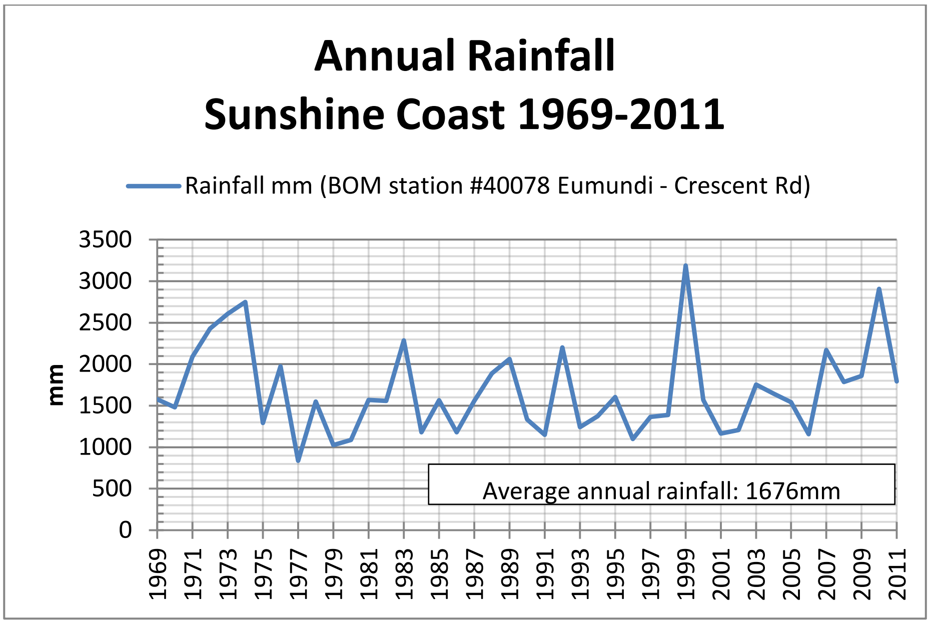


Figure 46. **Sunshine Coast: Annual Rainfall (data source: Eumundi – Crescent Road, station no. 40078).**

Similar to the Brisbane LGA case study, to determine the error introduced due to linear up-scaling of the output variables of the stochastic simulation, two cases were considered:

- Variable case, where the input variables of the rain water tank model were sampled from probability distributions (Table 23) and 1,000 household water demand profiles generated from the SDG model as described in section 3.2.1; and
- Average case, where input variables of the rain water tank model were the average values of the 10,000 sampled values derived from the probability distributions, given in Table 24.

Table 23. **Sunshine Coast: rainwater tank input parameter values.**

	Tank Size	**Effective Roof Area**	**Initial Loss(1)**	**Continuing Loss(1)**
Units	**KL**	**m^2**	**mm**	**%**
minimum	2.66	14.0	0	0
Mean	5.63	102.07	0.5	15
maximum	29.31	239.0	1.75	30
Probability distribution	Normal	Normal	Normal	Normal
Coefficient of Variation	0.8162	0.4584	1	0.3332
Standard Deviation	4.596	46.8	0.5	5
Sample size	438	108	0[1]	0[1]

Note #1: data not available for SEQ. Used Melbourne-based data reported in Xu *et al*. (2010).

Table 24. **Sunshine Coast: Average Case rainwater tank input parameter values.**

	Tank Size	Effective Roof Area	Initial Loss	Continuing Loss
Units	**kL**	**m^2**	**mm**	**%**
Mean of 10,000 sampled values used in the variable case	5.71	105.67	0.64	14.94

3.4.4.1. Tank Yield

The range of the variability shown by 10,000 values of tank yield was 15.72 to 154.13 kL/hh/yr. The mean was 50.25 kL/hh/yr and the standard deviation was 17.09 kL/hh/yr (Figure 47, Figure 48 and Appendix B).

The average case (i.e. the case with spatial lumping effect or the case that used average values for the input variables of the rainwater tank behavioural analysis) found 57.08 kL/hh/yr as the tank supply (Figure 48). This is a 14 percent overestimation when compared to the mean value of the case without spatial lumping effect.

Burr (4P) was the best-fit probability distribution function to the modelled tank yields in Sunshine Coast (Kolmogorov-Smirnov statistic and P-value = 0.0125, 0.09, respectively; Chi-Squared statistic, DF and P-value = 54.663, 13, 0, respectively; see Appendix B for details). The 50th percentile tank yield was 47.81 kL/hh/yr. Since the distribution of tank yield was not symmetrical (Figure 49), the median value was used to report the expected tank yield in absolute terms.

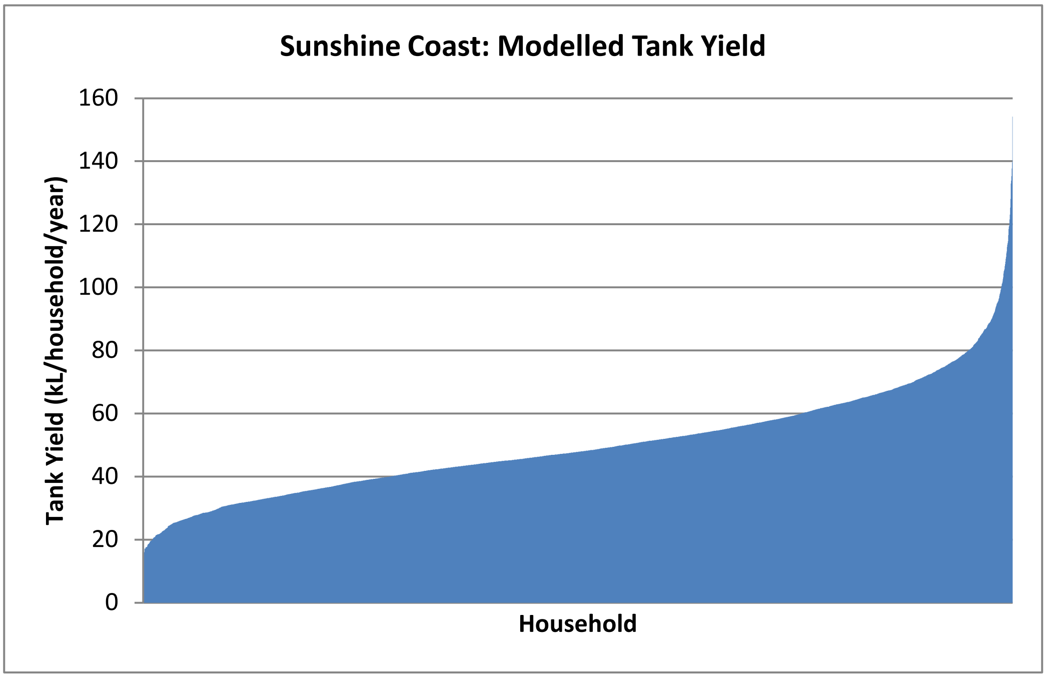


Figure 47. **Sunshine Coast: 10,000 tank yield values, generated from stochastic simulation.**

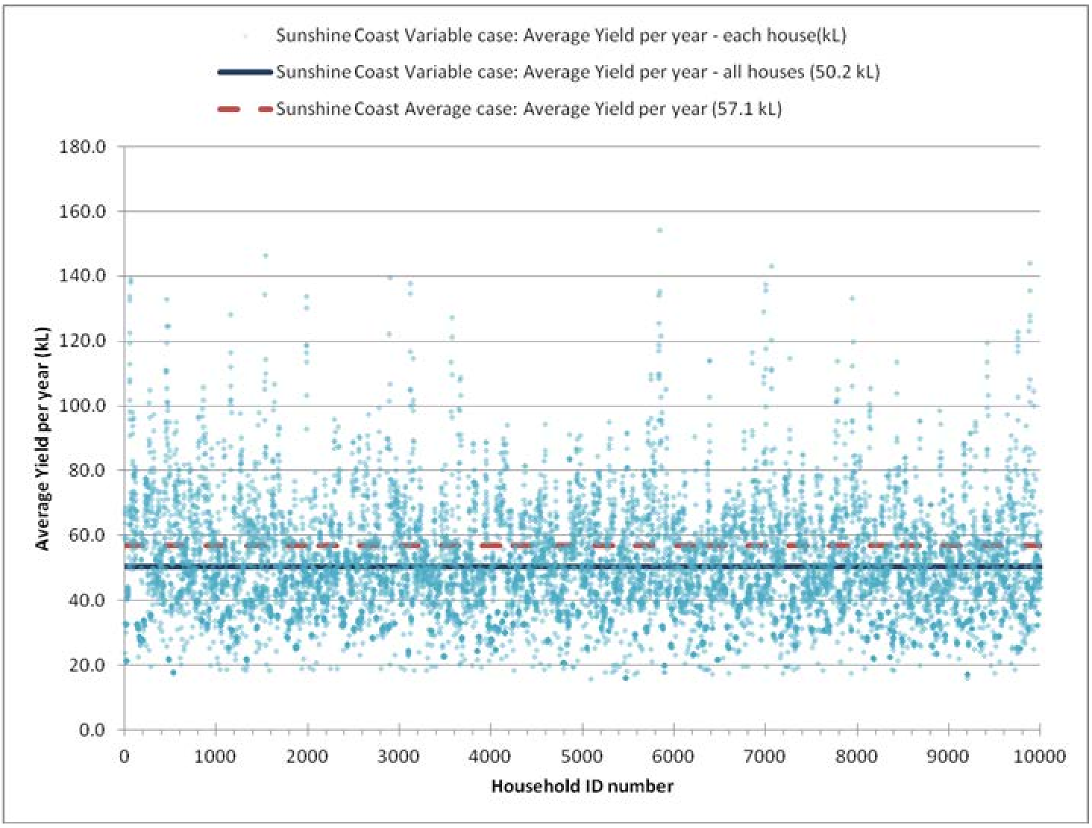
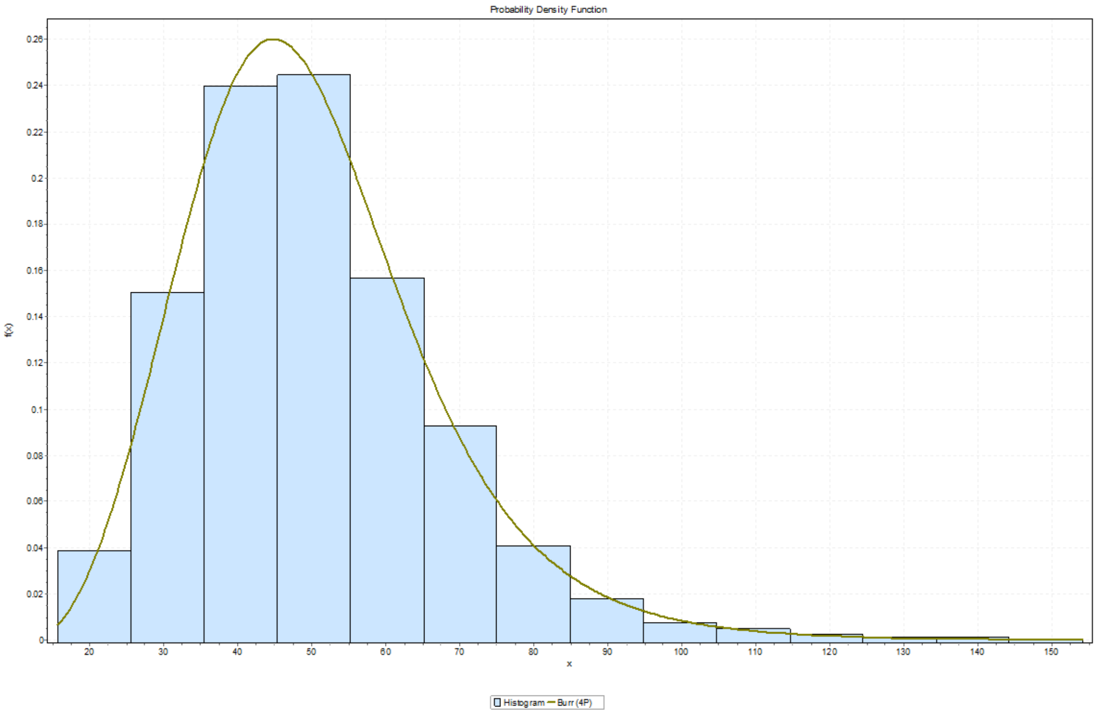


Figure 48. **Sunshine Coast: 10,000 tank yield values generated from stochastic simulation (blue dots), mean of 10,000 tank yields and the tank yield obtained by using average values of tank and water use characteristics.**



Percentile	Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max
Value	15.722	26.632	31.026	38.584	47.81	59.451	71.864	80.248	154.13

Figure 49. **Sunshine Coast: probability distribution and percentile values of tank yield (X axis represents tank yield in kL/hh/yr).**

3.4.4.2. Tank Overflow

The mean of 10,000 tank overflow values was 93.17 kL/hh/yr with a standard deviation of 56.58 kL/hh/yr (see Appendix C for descriptive statistics).

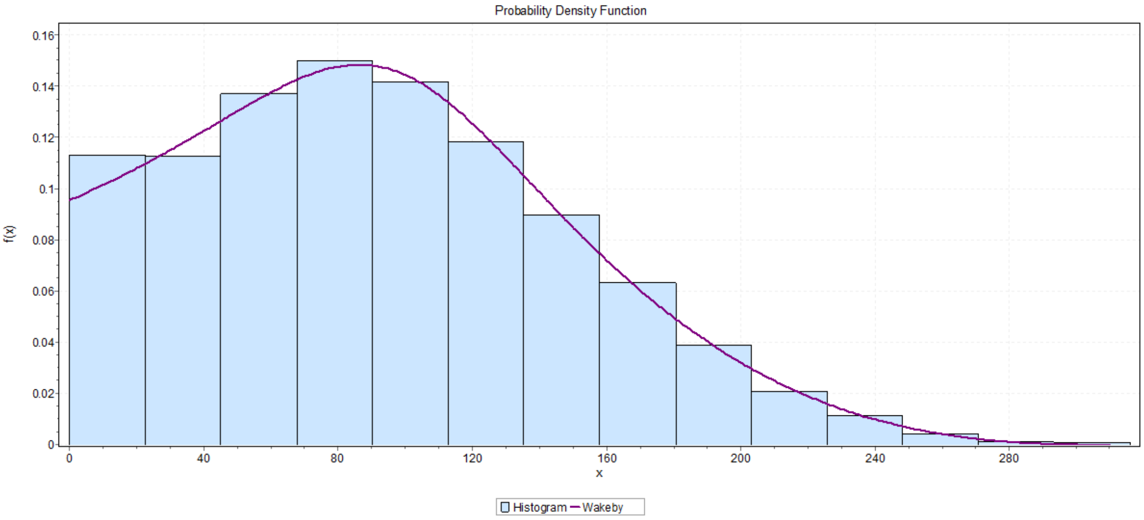
The average case (i.e. the case with spatial lumping effect or the case that used average values for the input variables of the rainwater tank behavioural analysis) found 86.14 kL/hh/yr as the tank overflow. This is an 8% underestimation when compared to the mean value of the case without spatial lumping effect.

The 10,000 tank overflow values in kL/hh/yr were fitted to a set of theoretical distribution functions using Easy Fit Professional (2010). Wakeby distribution was the best-fit probability distribution function to the modelled tank overflows in Sunshine Coast (Kolmogorov-Smirnov statistic and P-value = 0.00879, 0.42, respectively; see Appendix C for details). As shown in Figure 50, the distribution was not symmetrical, which indicated that 50th percentile value was appropriate to report the tank overflow in absolute terms. The 50th percentile value of the tank overflow was 88.45 kL/hh/yr.

Since the stochastic simulation was carried out on a daily basis, for absolute values of overflow, the overflow value obtained with daily simulations must be corrected by considering the results reported in Table 12 (i.e. the tank overflow obtained with daily simulation was about 30% more than the tank overflow obtained with hourly simulation). If a correction was applied to account for the error caused by daily simulation, the expected tank overflow for Brisbane LGA would be 68.04 kL/hh/yr.

In summary, for Sunshine Coast LGA, results indicated that:

- The expected tank yield was 47.81 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation;
- The expected overflow was 68.04 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation and corrected to account for the effect of daily simulation; and
- If average values were used for both tank and water use characteristics, the tank yield would be overestimated 14% and the tank overflow would be underestimated by 8%.



Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max	Mean	std dev
0.07	9.38	19.92	49.38	88.45	131.32	171.22	194.10	315.78	93.17	56.58

Figure 50. Sunshine Coast: probability distribution and percentile values of tank overflow (X axis represents tank overflow in kL/hh/yr).

3.5. Gold Coast

3.5.1. Probabilistic Representation of Household Demand

3.5.1.1. Calibration of the Stochastic Demand Model: Input Data

To calibrate the modified SDG model described in Chapter 2, household end use water demand data were sourced from Beal and Stewart (2011)'s residential end use measurement study. It provided end use water consumption statistics for 87 single family residential (SFR) households in Gold Coast. Due to the reasons explained in Brisbane LGA case study, we used 2010 winter data set for this study.

The end use water consumption statistics used to calibrate the modified SDG model to Gold Coast local government area were event mean volume for toilet, tap, dishwasher and clothes washer end uses in litres/event (Table 25), frequency of event for toilet, tap, shower, bath, dishwasher, clothes washer and garden water use (i.e. irrigation) end uses in events/day (Table 26), shower flow rate in litres/minute (Table 7) and shower duration in minutes (Table 8).

Table 25. **Gold Coast: end use event mean volume statistics (data source: Beal and Stewart, 2011).**

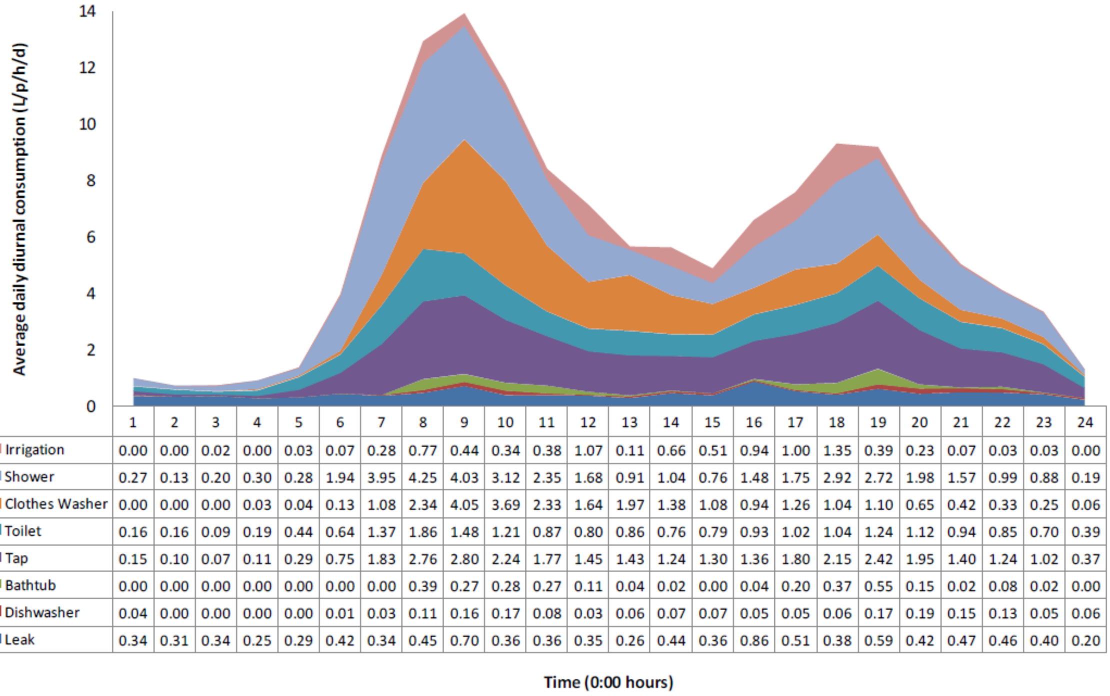
Gold Coast Statistics	Mean Volume of End Use Event (Litres/Event)				
	Half Flush	**Full Flush**	**Tap**	**Dishwasher**	**Clothes Washer**
Mean	4.12	8.00	1.98	4.26	106.88
Standard Deviation	1.37	2.15	0.54	9.55	77.51
Skewness	0.14	1.50	0.08	5.44	0.87

Table 26. **Gold Coast: end use frequency statistics (Beal and Stewart, 2011).**

Gold Coast Statistics	Frequency (Events Per Day)							
	Half Flush	**Full Flush**	**Tap**	**Shower**	**Bath**	**Dishwasher**	**Clothes Washer**	**Irrigation**
Mean	4.49	3.86	40.64	1.84	0.1	0.37	0.54	0.33
Standard Deviation	3.25	2.69	19.63	1.2	0.23	0.42	0.34	0.28
Skewness	0.83	1.25	0.77	1.55	2.48	1.28	0.3	0.94

The diurnal pattern of each end use was used to generate probabilities for triggering events for each end use (Figure 51). The probability distributions used for each end use (found through calibration) is shown in Table 9.

The time period of simulation was 1 January 1962 to 31 December 2011 (50 years). Like for Brisbane, for Gold Coast analysis, we generated 3,000 demand profiles.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Irrigation	0.00	0.00	0.02	0.00	0.03	0.07	0.28	0.77	0.44	0.34	0.38	1.07	0.11	0.66	0.51	0.94	1.00	1.35	0.39	0.23	0.07	0.03	0.03	0.00
Shower	0.27	0.13	0.20	0.30	0.28	1.94	3.95	4.25	4.03	3.12	2.35	1.68	0.91	1.04	0.76	1.48	1.75	2.92	2.72	1.98	1.57	0.99	0.88	0.19
Clothes Washer	0.00	0.00	0.00	0.03	0.04	0.13	1.08	2.34	4.05	3.69	2.33	1.64	1.97	1.38	1.08	0.94	1.26	1.04	1.10	0.65	0.42	0.33	0.25	0.06
Toilet	0.16	0.16	0.09	0.19	0.44	0.64	1.37	1.86	1.48	1.21	0.87	0.80	0.86	0.76	0.79	0.93	1.02	1.04	1.24	1.12	0.94	0.85	0.70	0.39
Tap	0.15	0.10	0.07	0.11	0.29	0.75	1.83	2.76	2.80	2.24	1.77	1.45	1.43	1.24	1.30	1.36	1.80	2.15	2.42	1.95	1.40	1.24	1.02	0.37
Bathtub	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.27	0.28	0.27	0.11	0.04	0.02	0.00	0.04	0.20	0.37	0.55	0.15	0.02	0.08	0.02	0.00
Dishwasher	0.04	0.00	0.00	0.00	0.00	0.01	0.03	0.11	0.16	0.17	0.08	0.03	0.06	0.07	0.07	0.05	0.05	0.06	0.17	0.19	0.15	0.13	0.05	0.06
Leak	0.34	0.31	0.34	0.25	0.29	0.42	0.34	0.45	0.70	0.36	0.36	0.35	0.26	0.44	0.36	0.86	0.51	0.38	0.59	0.42	0.47	0.46	0.40	0.20

Figure 51. **Gold Coast: average daily diurnal pattern (data source: Beal and Stewart, 2011).**

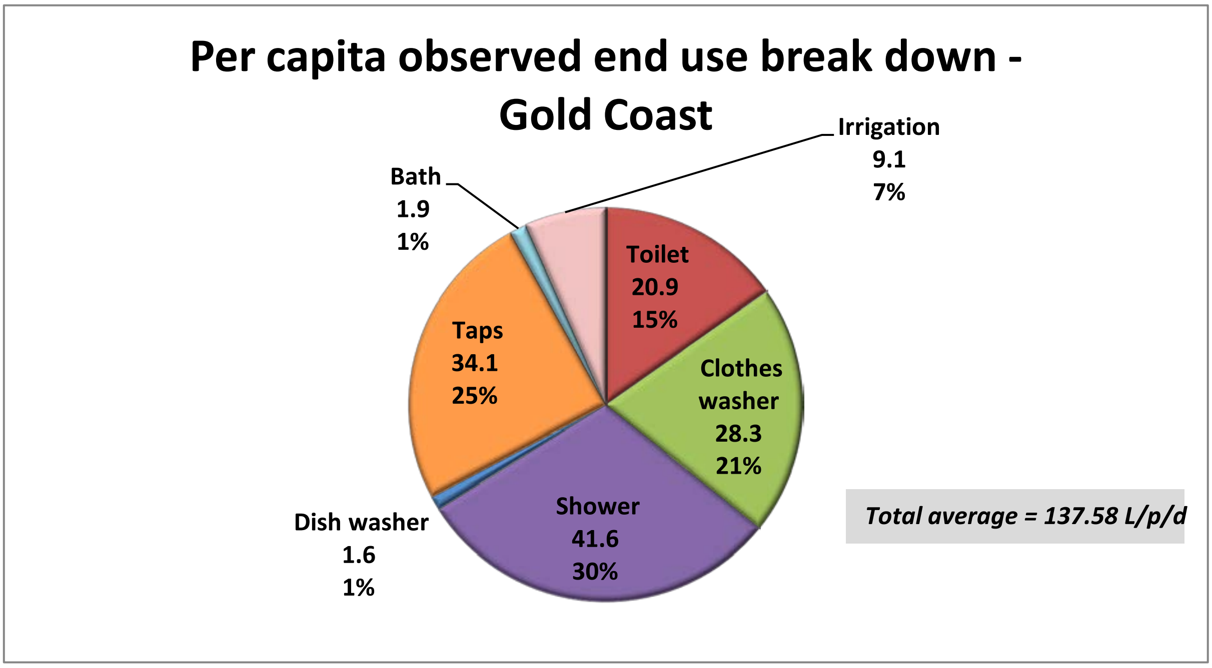
3.5.1.2. Calibration of the Stochastic Demand Model: Results

The observed and the modelled demand of each end use were compared in terms of mean, standard deviation, minimum value and maximum value, of each end use in litres/person/day (see Table 22).

Table 27. **Gold Coast: observed and modelled household end use demands.**

	Household End Use Water Demand in Litres/Person/Day							
	Toilet	**Clothes Washer**	**Shower**	**Dishwasher**	**Tap**	**Bathtub**	**Irrigation**	**Total**
Observed Mean	20.9	28.3	41.6	1.6	34.1	1.9	9.1	137.5
Modelled Mean	19.88	26.76	50.30	0.20	41.75	0.10	10.97	149.96
Observed Standard Deviation	12.58	28.32	33.13	1.99	16.41	4.9	13.45	79.81
Modelled Standard Deviation	10.1	24	54.98	0.31	11.2	0.01	7.42	28.16
Observed Min	2.51	0	2.26	0	7.03	0	0	26.09
Modelled Min	0	0	3.90	0	9.15	0.08	0	12.06
Observed Max	84.39	149.71	190.37	6.64	74.3	28.4	70.24	549.38
Modelled Max	58.37	137.63	519.49	2.15	73.38	0.13	36.05	365.42

Total water use and end use breakdown (Figure 52) and the distribution of each end use and the total water use (Figure 53). During the calibration, we paid attention to toilet, clothes washer and irrigation end uses (i.e. to obtain the modelled distribution of these end uses match with the observed distributions as closely as possible) because they were the end uses being supplemented with rainwater as per Queensland Development Code 3.2. The distributions of toilet, clothes washer and irrigation demands are shown (i.e. Figure 53).



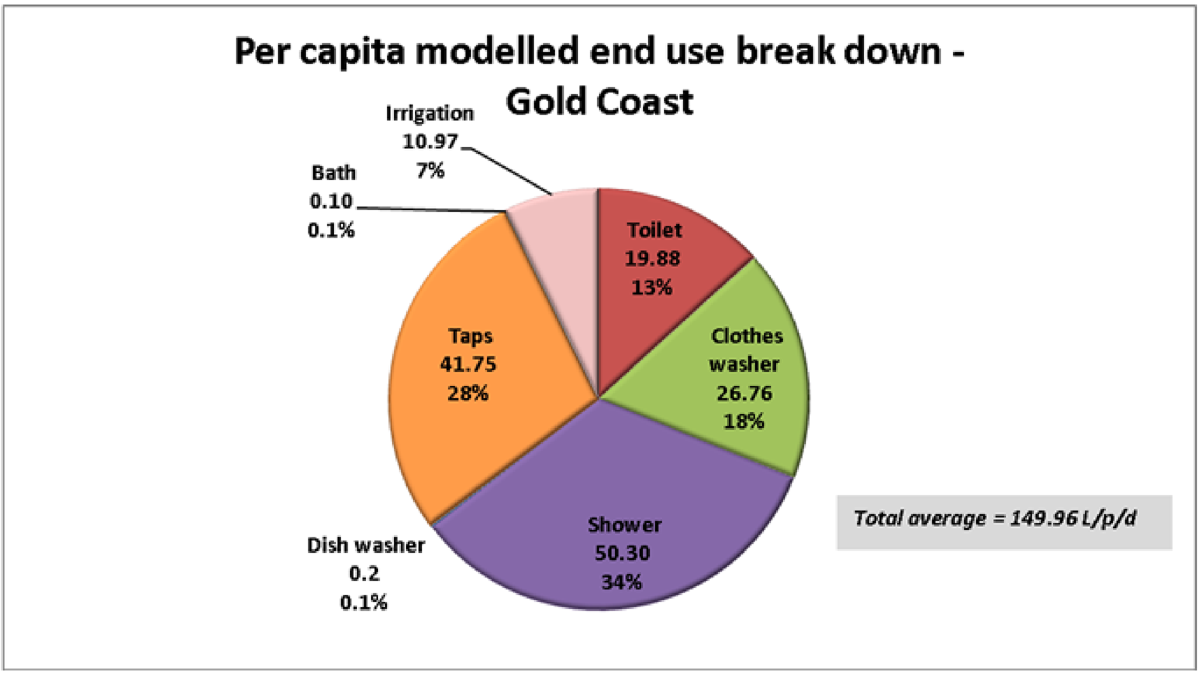


Figure 52. **Gold Coast: comparison of observed (top) and modelled (bottom) total water use and per capita end use breakdown.**

The results showed that the average household consumption during the measured period (i.e. 14-28 June 2010) without considering leaks was 137.58 L/p/d. The simulated or modelled value of household consumption was 149.96 L/p/d. Comparison of the observed and modelled end use breakdown indicated that modelled demands were of similar order of magnitude to the observed demands.

Upon calibrating the SDG model, 1,000 probable demand time series of 50 years were generated for each end use, in one minute time scale. These were then aggregated to match with the time step of simulation of rainwater tank simulation and used as probable values for the input variable on 'demand' in the rainwater tank model. This was to undertake tank supply, overflow and water quality analysis in line with the study objectives stated in Chapter 1.

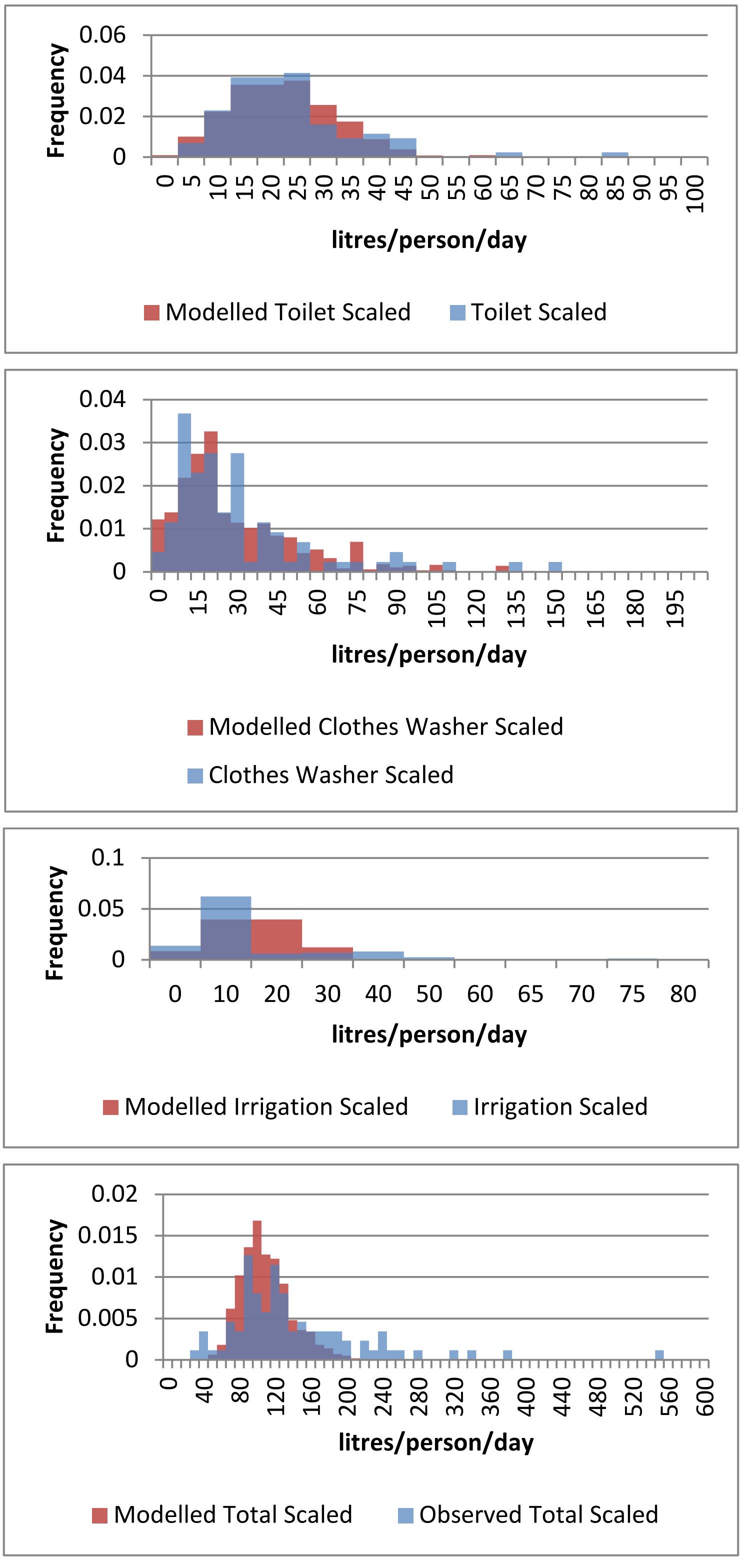


Figure 53. **Gold Coast: comparison of the frequency distributions of observed and modelled toilet, clothes washer, irrigation and total per capita water use.**

3.5.2. Probabilistic Representation of Rainwater Tank Sizes

Tank sizes were sourced from Biermann *et al.* (2012). The data sample contained 31 tanks. The effective sizes of tanks in this sample ranged from 4.12 kL to 7.87 kL, with a mean of 5.61 kL and a standard deviation of 0.86 kL (Figure 54 and Appendix A).

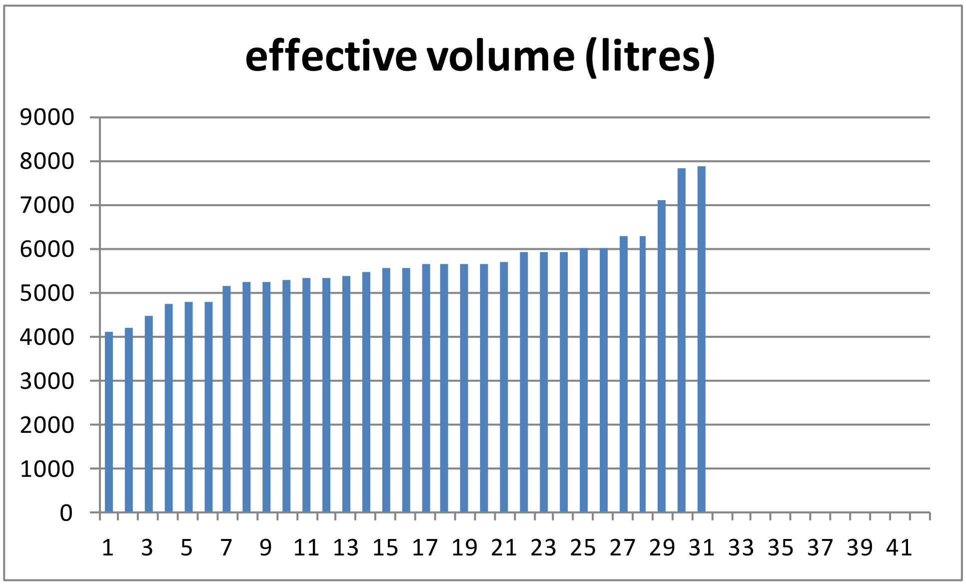


Figure 54. **Gold Coast: tank sizes.**

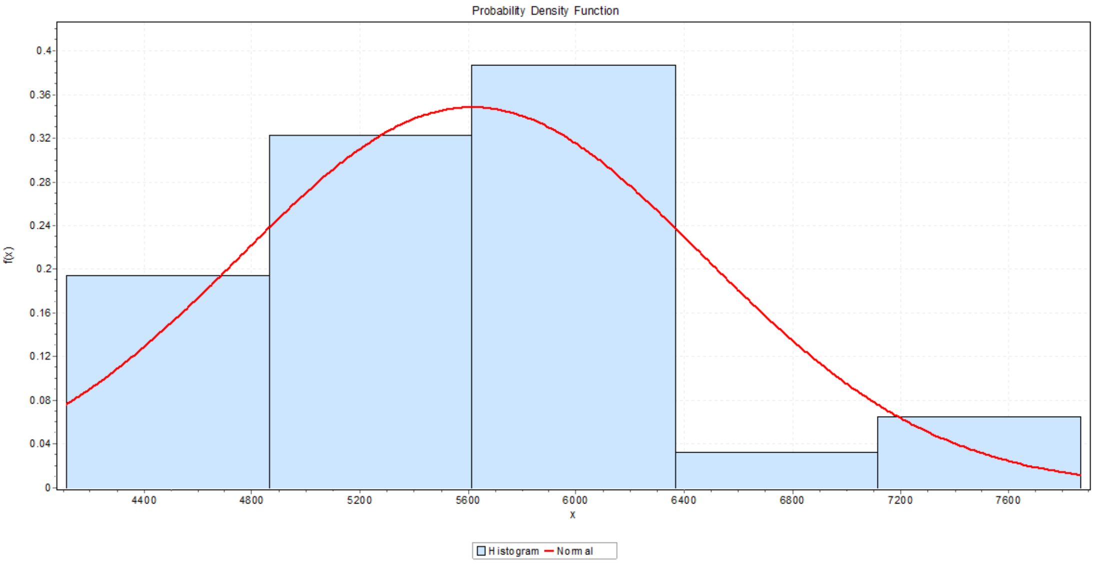


Figure 55. **Gold Coast: Fitting tank size data to the normal distribution (x axis represents tank sizes in litres).**

Similar to the Brisbane case study, the acceptability of the normal distribution was examined using Easy Fit Professional (2010), in order to understand how the observed data deviated from the normal distribution. The goodness of fit analysis indicated that the observed tank sizes were normally distributed (Kolmogorov-Smirnov statistic and P-value = 0.1628, 0.35, respectively; Chi-Squared statistic, DF and P-value = 1.4467, 3, 0.69, respectively; see Appendix A for details). Fitting of the observed data on tank sizes to the normal distribution is shown in Figure 55.

3.5.3. Probabilistic Representation of Roof Areas

Roof areas were sourced from Biermann *et al.* (2012). The data sample contained 31 tanks. The roof areas in this sample ranged from 29 m^2 to 197 m^2 with a mean of 97.61 m^2 and a standard deviation of 44.22 m^2 (Figure 56 and Appendix A).

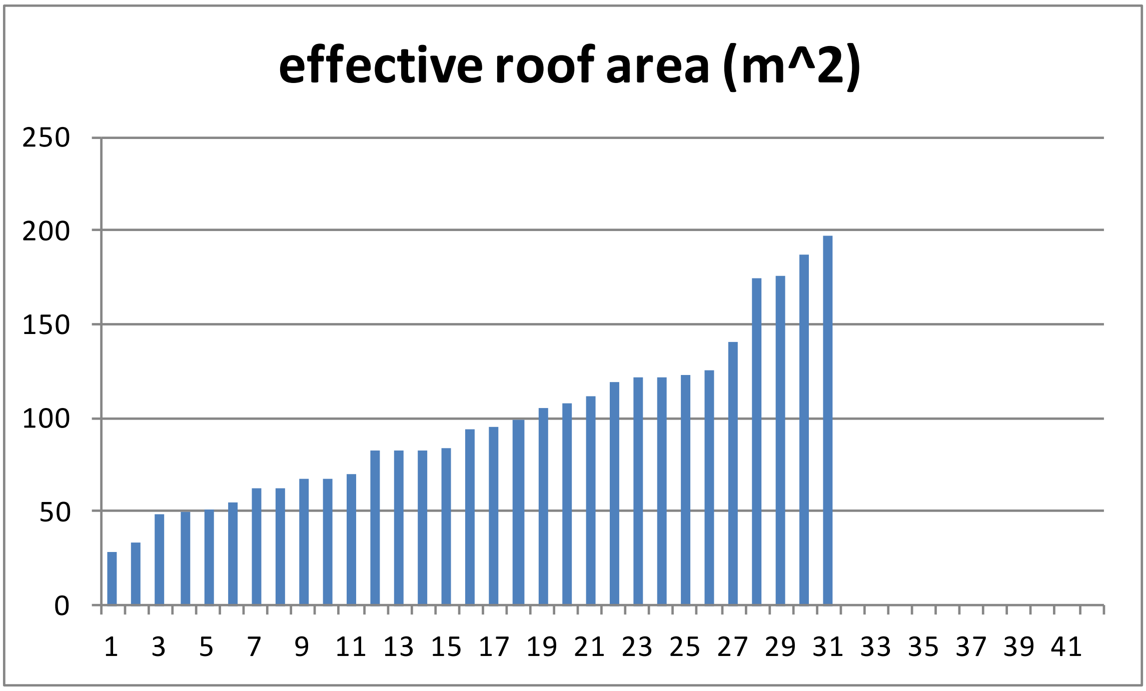


Figure 56. **Gold Coast: Distribution of roof areas.**

Similar to the Brisbane case study, the acceptability of the normal distribution was examined using Easy Fit Professional (2010), in order to understand how the observed data deviated from the normal distribution. The goodness of fit analysis indicated that the observed roof areas were normally distributed (Kolmogorov-Smirnov statistic and P-value = 0.10652, 0.84, respectively; Chi-Squared statistic, DF and P-value = 0.57784, 3, 0.97, respectively; see Appendix A for details). Fitting of the observed data on roof areas to the normal distribution is shown in Figure 57.

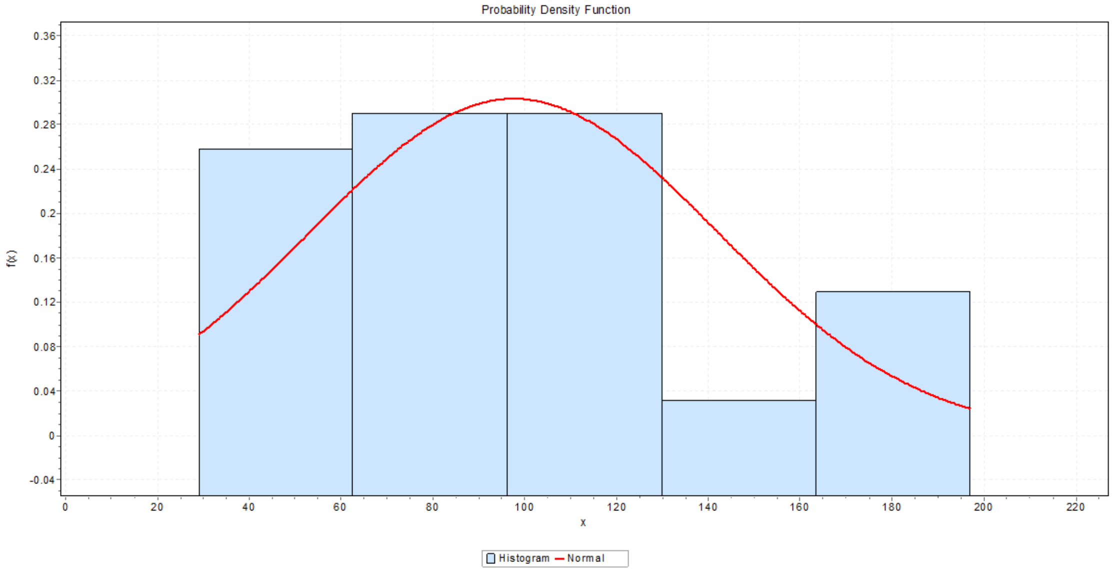


Figure 57. **Gold Coast: Fitting roof area data to the normal distribution (x axis represents roof areas in m^2).**

3.5.4. Stochastic Simulation

The period of simulation was 1 January 1962 to 31 December 2011 (50 years). Climate data were sourced from BOM station: 40160, Nerang Gilston Road (Figure 58).

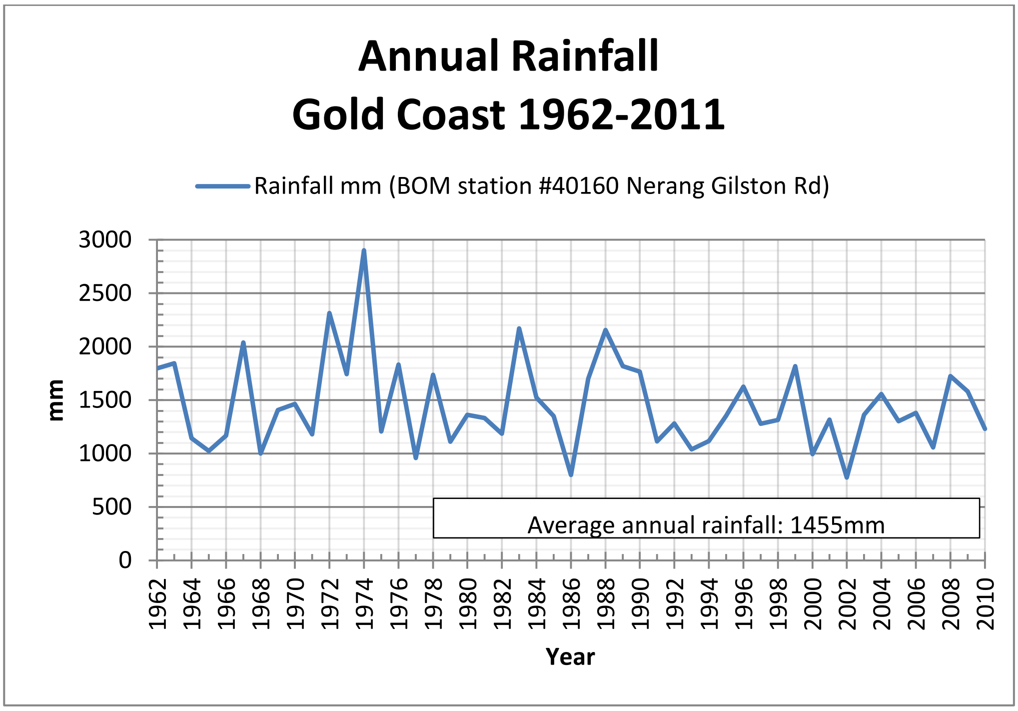


Figure 58. Gold Coast: Annual Rainfall (data source: Nerang – Gilston Road, station no. 40160).

Table 28. Gold Coast: rainwater tank parameter values.

	Tank Size	Effective Roof Area	Initial Loss[1]	Continuing Loss[1]
Units	**KL**	**m^2**	**mm**	**%**
minimum	4.12	29.00	0	0
Mean	5.61	97.61	0.5	15
maximum	7.87	197.00	1.75	30
Probability distribution	Normal	Normal	Normal	Normal
Standard Deviation	0.86	44.21	0.5	5
Sample size	31	31	0[1]	0[1]

Note #1: data not available for SEQ. Used Melbourne-based data reported in Xu *et al*. (2010).

Similar to the Brisbane LGA case study, to determine the error introduced due to linear up-scaling of the output variables of the stochastic simulation, two cases were considered:

- Variable case, where the input variables of the rain water tank model were sampled from probability distributions (Table 28) and 1,000 household water demand profiles generated from the SDG model as described in section 3.2.1; and
- Average case, where input variables of the rain water tank model were the average values of the 10,000 sampled values derived from the probability distributions, given in Table 29.

Table 29. **Gold Coast: Average Case rainwater tank parameter values.**

	Tank Size	Effective Roof Area	Initial Loss	Continuing Loss
Units	**kL**	**m^2**	**mm**	**%**
Mean of 10,000 sampled values used in the variable case	5.68	101.76	0.64	14.92

3.5.4.1. Tank Yield

The range of the variability shown by 10,000 values of tank yield was 5.44 to 103.61 kL/hh/yr. The mean was 44.38 kL/hh/yr and the standard deviation was 14.49 kL/hh/yr (Figure 59, Figure 60 and Appendix B).

The average case (i.e. the case with spatial lumping effect or the case that used average values for the input variables of the rainwater tank behavioural analysis) found 49.03kL/hh/yr as the tank supply (Figure 60). This is a 10 percent overestimation when compared to the mean value of the case without spatial lumping effect (i.e. 44.38 kL/hh/yr).

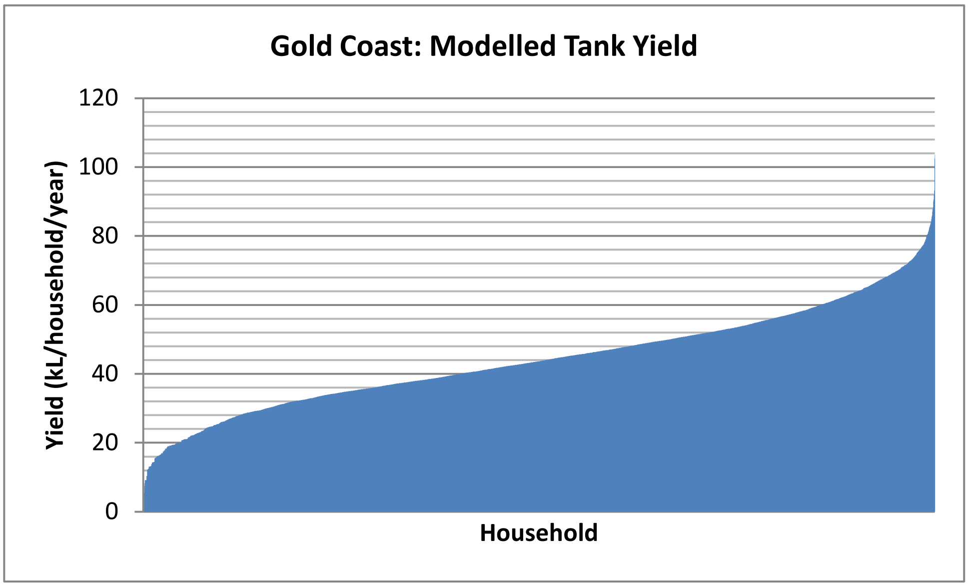


Figure 59. **Gold Coast: 10,000 tank yield values, generated from stochastic simulation.**

Lognormanl (3P) was the best-fit probability distribution function to the modelled tank yields in Gold Coast (Kolmogorov-Smirnov statistic and P-value = 0.01006, 0.26, respectively; Chi-Squared statistic, DF and P-value = 46.957, 13, 0, respectively; see Appendix B for details). The 50th percentile tank yield was 43.66 kL/hh/yr. Since the distribution of tank yield was not symmetrical (Figure 61), the median value was used to report the tank yield in absolute terms.

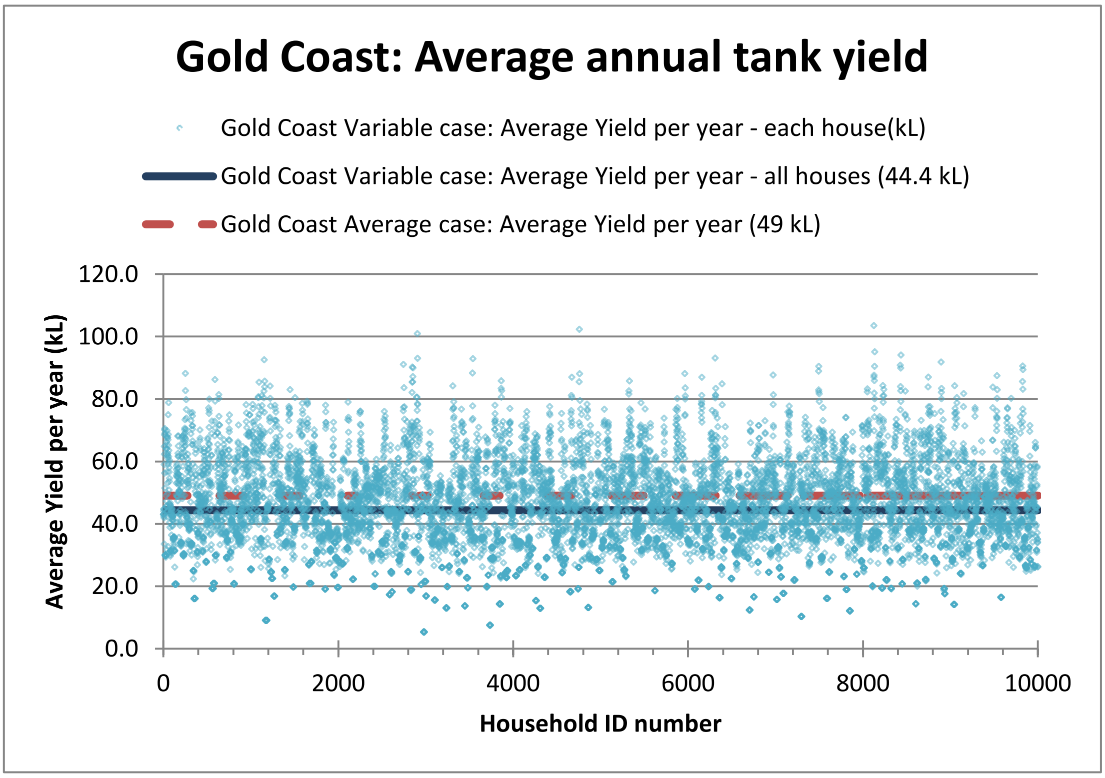
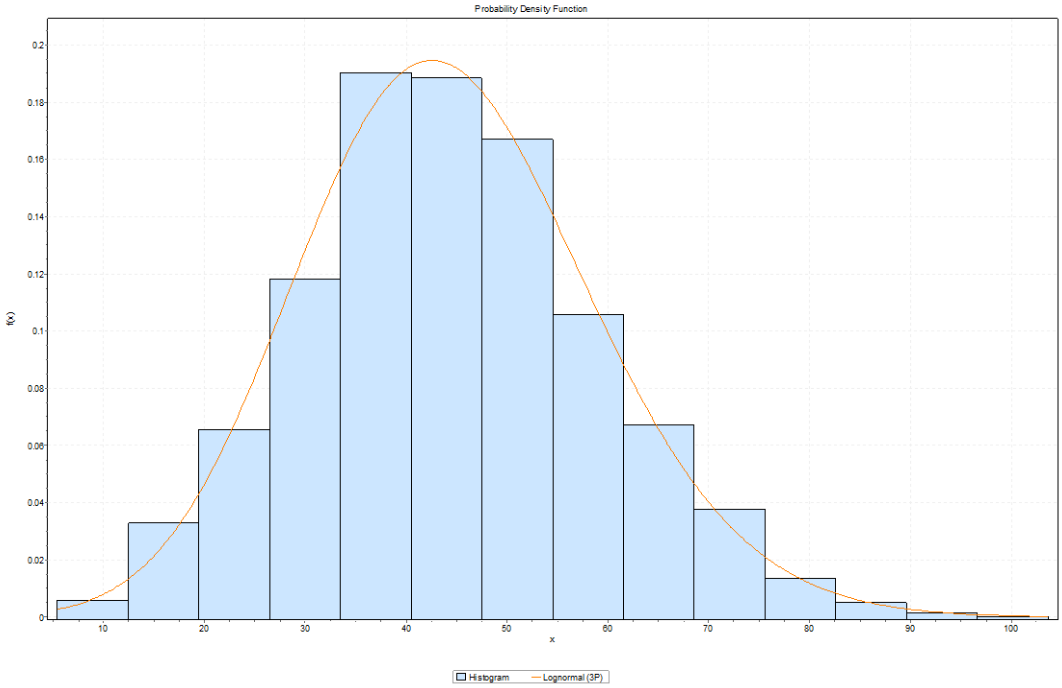


Figure 60. Gold Coast: 10,000 tank yield values generated from stochastic simulation (blue dots), mean of 10,000 tank yields and the tank yield obtained by using average values of tank and water use characteristics.



Percentile	Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max
Value	5.4383	20.788	26.071	34.61	43.655	53.524	63.768	69.575	103.61

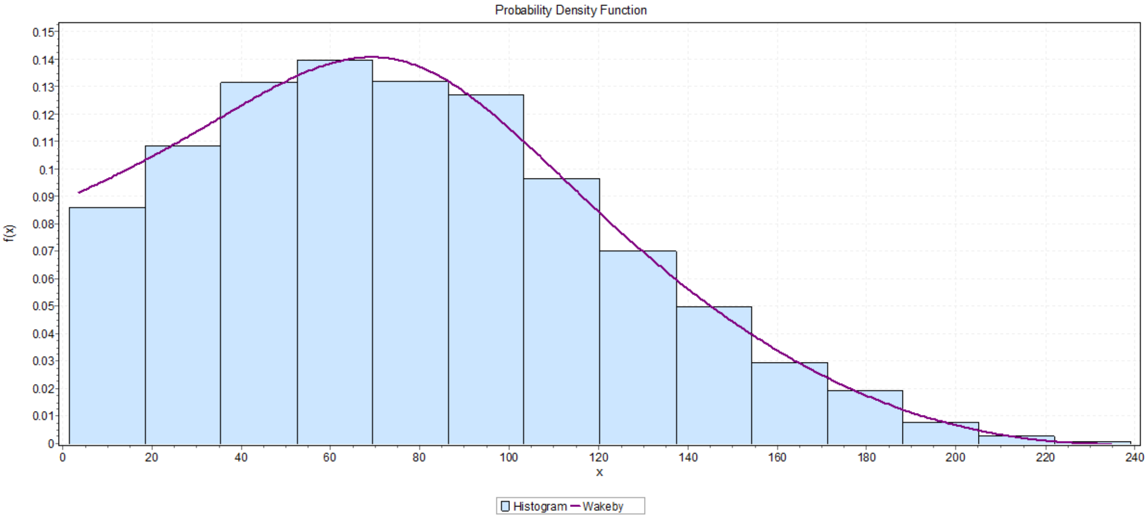
Figure 61. Gold Coast: probability distribution and percentile values of tank yield (X axis represents tank yield in kL/hh/yr).

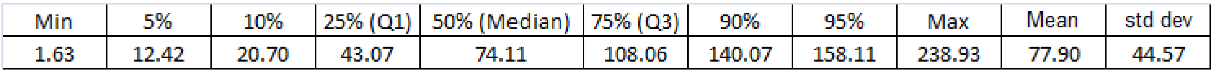
3.5.4.2. Tank Overflow

The mean of 10,000 tank overflow values was 77.90 kL/hh/yr (see Appendix C for descriptive statistics). The average case found the overflow of 73.06 kL/hh/yr. This was a 6% percent underestimation of overflow when compared to the mean of the variable case.

Wakeby distribution was the best-fit probability distribution function to the modelled tank overflows in Gold Coast (Kolmogorov-Smirnov statistic and P-value = 0.00556, 0.91, respectively; see Appendix C for details). Since the distribution was not symmetrical (Figure 62), the median value was used to report the overflow, i.e. 74.11 kL/hh/yr.

Since the stochastic simulation was carried out on a daily basis, for absolute values of overflow, the overflow value obtained with daily simulations must be corrected by considering the results reported in Table 12 (i.e. the tank overflow obtained with daily simulation was about 30% more than the tank overflow obtained with hourly simulation). By accounting for the error caused by daily simulation, the expected tank overflow was 57.01 kL/hh/yr.





Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max	Mean	std dev
1.63	12.42	20.70	43.07	74.11	108.06	140.07	158.11	238.93	77.90	44.57

Figure 62. **Gold Coast: probability distribution and percentile values of tank overflow (X axis represents tank overflow in kL/hh/yr).**

In summary, for Gold Coast LGA, results indicated that:

- The expected tank yield was 43.66 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation;
- The expected overflow was 57.01 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation and corrected to account for the effect of daily simulation; and
- If average values were used for both tank and water use characteristics, the tank yield would be overestimated 10% and the tank overflow would be underestimated by 6%.

3.6. Ipswich

3.6.1. Probabilistic Representation of Household Demand

3.6.1.1. Calibration of the Stochastic Demand Model: Input Data

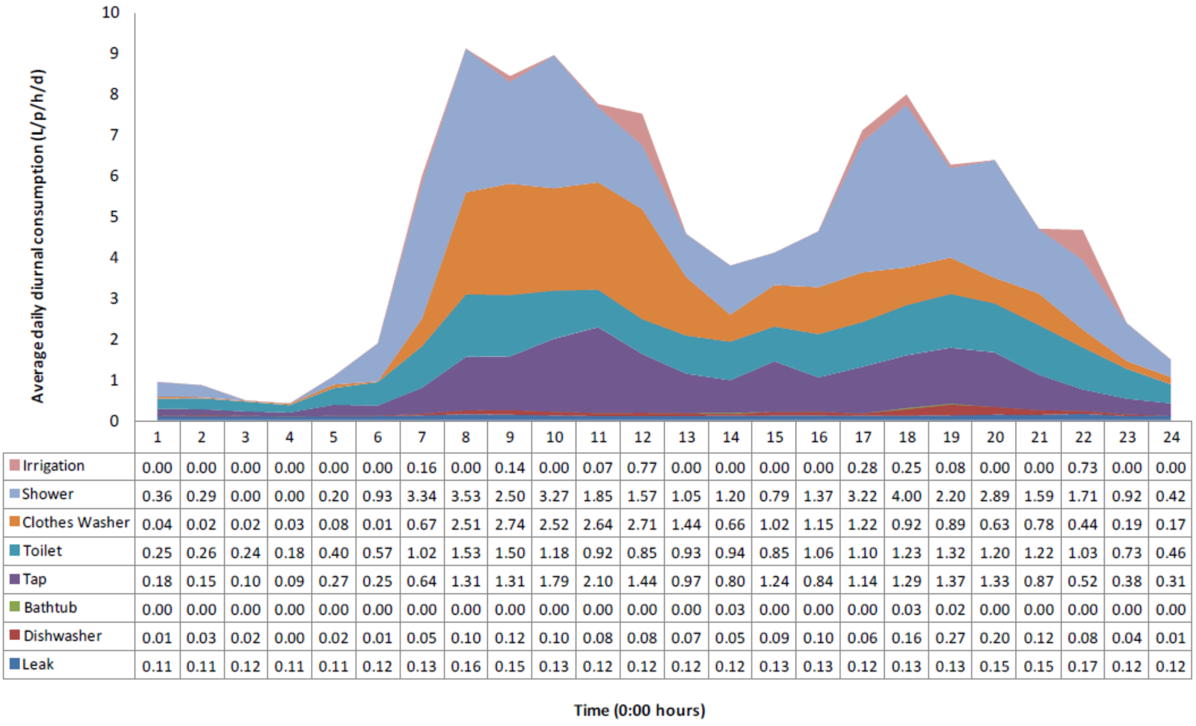
To calibrate the modified SDG model described in Chapter 2, household end use water demand data were sourced from Beal and Stewart's (2011) residential end use measurement study. It provided end use water consumption statistics for 37 single family residential (SFR) households. Due to the reasons explained in Brisbane LGA case study, we used 2010 winter data set for this study.

Table 30. **Ipswich: end use event mean volume statistics (data source: Beal and Stewart, 2011).**

Ipswich Statistics	**Mean Volume of End Use Event (Litres/Event)**				
	Half Flush	**Full Flush**	**Tap**	**Dishwasher**	**Clothes Washer**
Mean	4.68	8.92	1.48	4.14	113.79
Standard Deviation	1.34	2.12	1.01	5.31	73.67
Skewness	-1.00	0.09	2.62	1.03	0.40

Table 31. **Ipswich: end use frequency statistics (Beal and Stewart, 2011).**

Ipswich Statistics	**Frequency (Events Per Day)**							
	Half Flush	**Full Flush**	**Tap**	**Shower**	**Bath**	**Dishwasher**	**Clothes Washer**	**Irrigation**
Mean	6.14	3.58	46.66	2.11	0.01	0.67	0.56	0.05
Standard Deviation	4.21	2.77	27.69	1.43	0.05	1.05	0.54	0.15
Skewness	0.89	1.59	1.11	0.91	5.92	2.25	2.43	3.98



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Irrigation	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.14	0.00	0.07	0.77	0.00	0.00	0.00	0.00	0.28	0.25	0.08	0.00	0.00	0.73	0.00	0.00
Shower	0.36	0.29	0.00	0.00	0.20	0.93	3.34	3.53	2.50	3.27	1.85	1.57	1.05	1.20	0.79	1.37	3.22	4.00	2.20	2.89	1.59	1.71	0.92	0.42
Clothes Washer	0.04	0.02	0.02	0.03	0.08	0.01	0.67	2.51	2.74	2.52	2.64	2.71	1.44	0.66	1.02	1.15	1.22	0.92	0.89	0.63	0.78	0.44	0.19	0.17
Toilet	0.25	0.26	0.24	0.18	0.40	0.57	1.02	1.53	1.50	1.18	0.92	0.85	0.93	0.94	0.85	1.06	1.10	1.23	1.32	1.20	1.22	1.03	0.73	0.46
Tap	0.18	0.15	0.10	0.09	0.27	0.25	0.64	1.31	1.31	1.79	2.10	1.44	0.97	0.80	1.24	0.84	1.14	1.29	1.37	1.33	0.87	0.52	0.38	0.31
Bathtub	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.00
Dishwasher	0.01	0.03	0.02	0.00	0.02	0.01	0.05	0.10	0.12	0.10	0.08	0.08	0.07	0.05	0.09	0.10	0.06	0.16	0.27	0.20	0.12	0.08	0.04	0.01
Leak	0.11	0.11	0.12	0.11	0.11	0.12	0.13	0.16	0.15	0.13	0.12	0.12	0.12	0.12	0.13	0.13	0.12	0.13	0.13	0.15	0.15	0.17	0.12	0.12

Figure 63. **Ipswich: average daily diurnal pattern (data source: Beal and Stewart, 2011).**

The end use water consumption statistics used to calibrate the modified SDG model to Ipswich local government area were event mean volume for toilet, tap, dishwasher and clothes washer end uses in litres/event (Table 30), frequency of event for toilet, tap, shower, bath, dishwasher, clothes washer and garden water use (i.e. irrigation) end uses in events/day (Table 31), shower flow rate in litres/minute and shower duration in minutes. The diurnal pattern of each end use was used to generate probabilities for triggering events for each end use (Figure 63). The probability distributions used for each end use (found through calibration) is shown in Table 9.

The time period of simulation was 1 January 1962 to 31 December 2011 (50 years). As for Brisbane, for the Ipswich analysis, we generated 3,000 demand profiles.

3.6.1.2. Calibration of the Stochastic Demand Model: Results

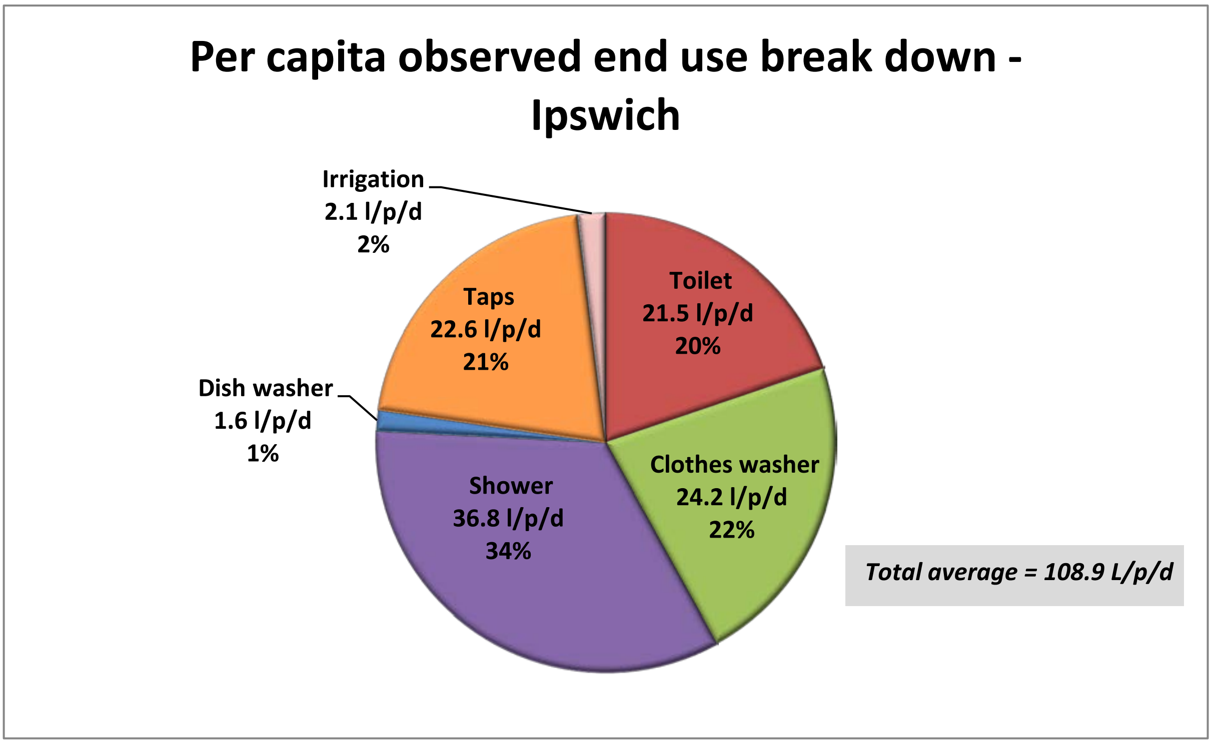
The observed and the modelled demand of each end use were compared in terms of mean, standard deviation, minimum value and maximum value, of each end use in litres/person/day (see Table 22), total water use and end use breakdown (Figure 42) and the distribution of each end use and the total water use (Figure 64). During the calibration, we paid attention to toilet, clothes washer and irrigation end uses (i.e. to obtain the modelled distribution of these end uses match with the observed distributions as closely as possible) because they were the end uses being supplemented with rainwater as per Queensland Development Code 3.2. The distributions of toilet, clothes washer and irrigation demands are shown (i.e. Figure 65).

As indicated by the results, the average household consumption during the measured period (i.e. 14-28 June 2010) without considering leaks was 108.9 L/p/d. The simulated or modelled value of household consumption was 107.6 L/p/d. Comparison of the observed and modelled end use breakdown indicated that modelled demands were of similar order of magnitude to the observed demands.

Table 32. **Ipswich: observed and modelled household end use demands.**

	Household End Use Water Demand in Litres/Person/Day							
	Toilet	Clothes Washer	Shower	Dishwasher	Tap	Bathtub	Irrigation	Total
Observed Mean	21.52	24.19	36.82	1.62	22.57	0.05	1.7	108.30
Modelled Mean	23.20	23.58	31.31	1.54	24.57	1.24	2.13	107.58
Observed Standard Deviation	11.88	17.82	23.37	1.90	18.21	0.30	5.55	46.45
Modelled Standard Deviation	11.95	31.03	12.76	3.82	0.24	0.09	2.54	36.14
Observed Min	8.8	4.2	2.9	0.0	4.0	0.0	0.0	38.5
Modelled Min	0.0	0.0	0.0	0.0	23.9	1.0	0.0	33.6
Observed Max	148.7	192.6	250.8	47.2	83.7	76.6	98.2	590.9
Modelled Max	68.7	270.2	67.7	30.0	25.3	1.6	13.2	625.8

Upon calibrating the SDG model, 1,000 probable demand time series of 50 years were generated for each end use, in a one-minute time scale. These were then aggregated to match with the time-step of simulation of rainwater tank simulation and used as probable values for the input variable on ‘demand’ in the rainwater tank model. This was to undertake tank supply, overflow and water quality analysis in line with the study objectives stated in Chapter 1.



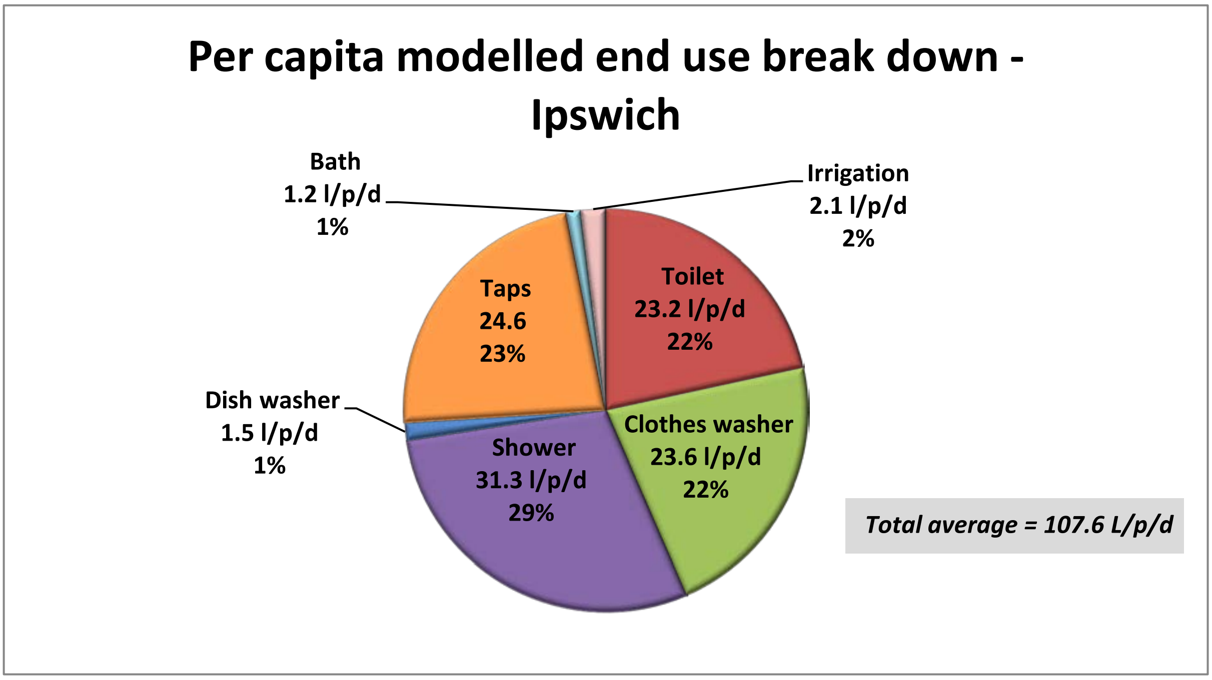


Figure 64. **Ipswich: comparison of observed (top) modelled (bottom) total water use and per capita end use breakdown.**

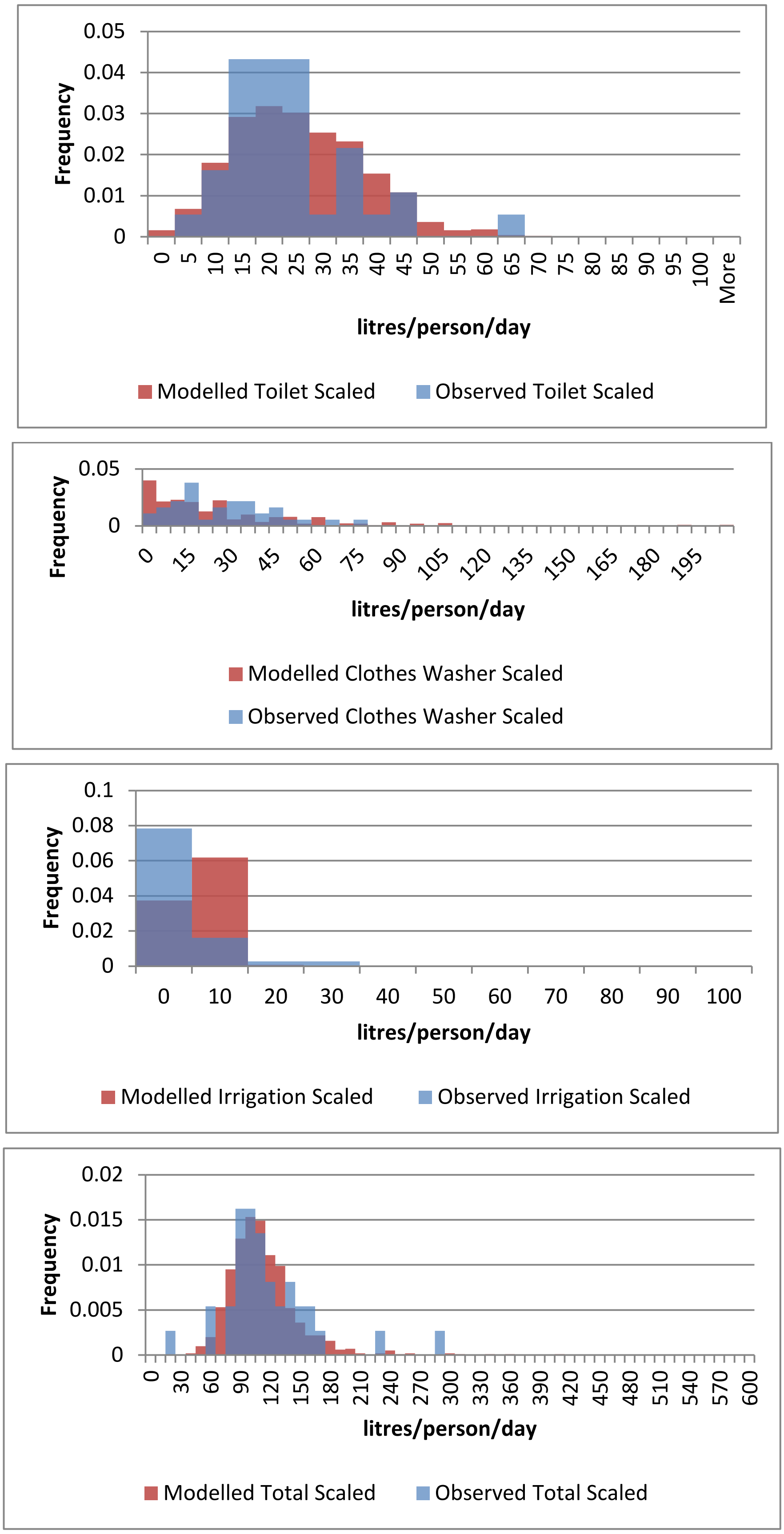


Figure 65. **Ipswich: comparison of the frequency distributions of observed and modelled toilet, clothes washer, irrigation and total per capita water use.**

3.6.2. Probabilistic Representation

Tank sizes were sourced from the Home and garden Waterwise Rebate Scheme (HWRS), provided by the QWC. The data sample contained 258 tanks and their nominal sizes. The relationship described under Brisbane LGA case study was used to convert nominal tank sizes to effective tank sizes. The effective sizes of tanks in this sample ranged from 2.66 kL to 23.98 kL, with a mean of 6.67 kL and a standard deviation of 4.19 kL (Figure 66) (see Appendix A for descriptive statistics).

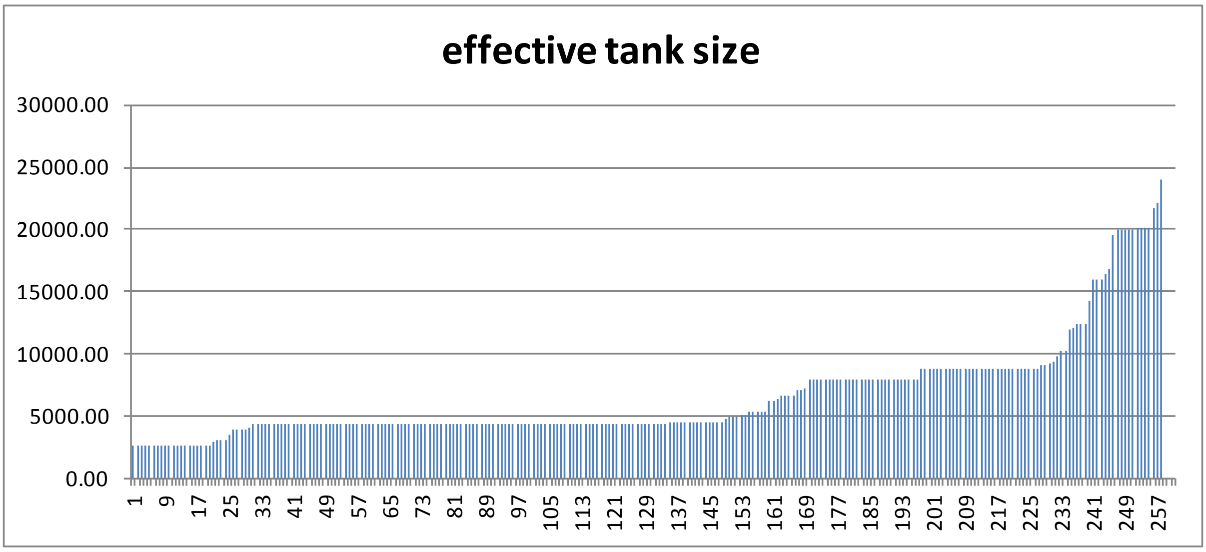


Figure 66. **Ipswich: tank sizes.**

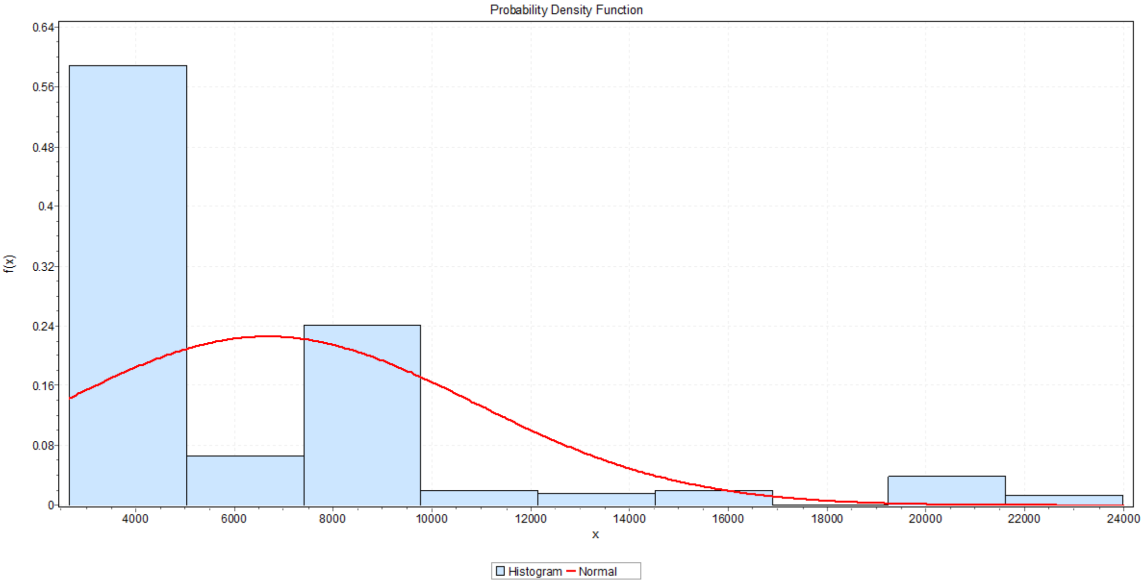


Figure 67. **Ipswich: Fitting tank size data to the normal distribution (x axis represents tank sizes in litres).**

Similar to the Brisbane case study, the acceptability of the normal distribution was examined using Easy Fit Professional (2010), in order to understand how the observed data deviated from the normal distribution. The goodness of fit analysis indicated that the observed tank sizes were not normally distributed (Kolmogorov-Smirnov statistic and P-value = 0.2679, 0, respectively; Chi-Squared statistic, DF and P-value = 537.81, 7, 0, respectively; see Appendix A for details).

Deviation of the observed data on tank sizes from the normal distribution is shown in Figure 45. The effect of this deviation was generation of a lower proportion of 3-5 kL tanks a higher proportion of 6-7 kL and 10-14 kL tanks compared to those of the observed sample.

3.6.3. Probabilistic Representation of Roof Areas

Roof areas are not available. We used the Caboolture and Pine Rivers (i.e. Moreton Bay) sample of 108 houses sourced from Biermann *et al.* (2012).

3.6.4. Stochastic Simulation

The period of simulation was 1 January 1962 to 31 December 2011 (50 years). Climate data were sourced from BOM station: 40101 (Figure 58).

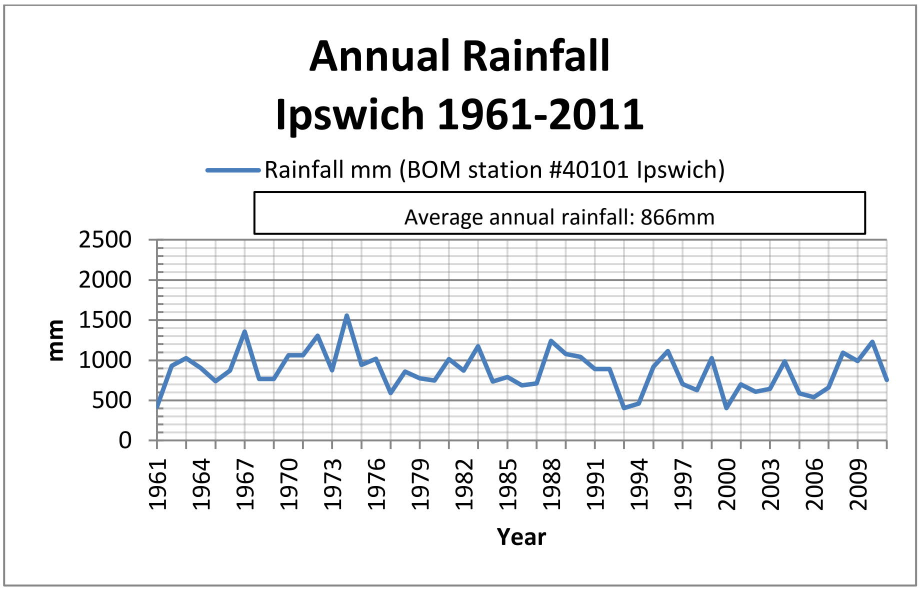


Figure 68. Ipswich: Annual Rainfall (data source: BOM station no. 40101).

Table 33. Ipswich: rainwater tank parameter values.

	Tank Size	Effective Roof Area	Initial Loss[1]	Continuing Loss[1]
Units	**KL**	**m^2**	**mm**	**%**
minimum	2.66	14.0	0	0
Mean	6.67	102.07	0.5	15
maximum	23.98	239.0	1.75	30
Probability distribution	Normal	Normal	Normal	Normal
Standard Deviation	4.19	46.8	0.5	5
Sample size	438	108	0[1]	0[1]

Note #1: data not available for SEQ. Used Melbourne-based data reported in Xu *et al*. (2010).

Similar to the Brisbane LGA case study, to determine the error introduced due to linear up-scaling of the output variables of the stochastic simulation, two cases were considered:

- Variable case, where the input variables of the rain water tank model were sampled from probability distributions (Table 33) and 1,000 household water demand profiles generated from the SDG model as described in section 3.2.1; and
- Average case, where input variables of the rain water tank model were the average values of the 10,000 sampled values derived from the probability distributions, given in Table 34.

Table 34. Ipswich: Average Case rainwater tank parameter values.

	Tank Size	Effective Roof Area	Initial Loss	Continuing Loss
Units	**kL**	**m^2**	**mm**	**%**
Mean of 10,000 sampled values used in the variable case	7.92	105.13	0.63	14.94

3.6.4.1. Tank Yield

The range of the variability shown by 10,000 values of tank yield was 0 to 103.57 kL/hh/yr. The mean was 34.53 kL/hh/yr and the standard deviation was 14.59 kL/hh/yr (Figure 69, Figure 70 and Appendix B).

The average case (i.e. the case with spatial lumping effect or the case that used average values for the input variables of the rainwater tank behavioural analysis) found 42.19 kL/hh/yr as the tank supply (Figure 70). This is a 22 percent overestimation when compared to the mean value of the case without spatial lumping effect (i.e. 34.53 kL/hh/yr).

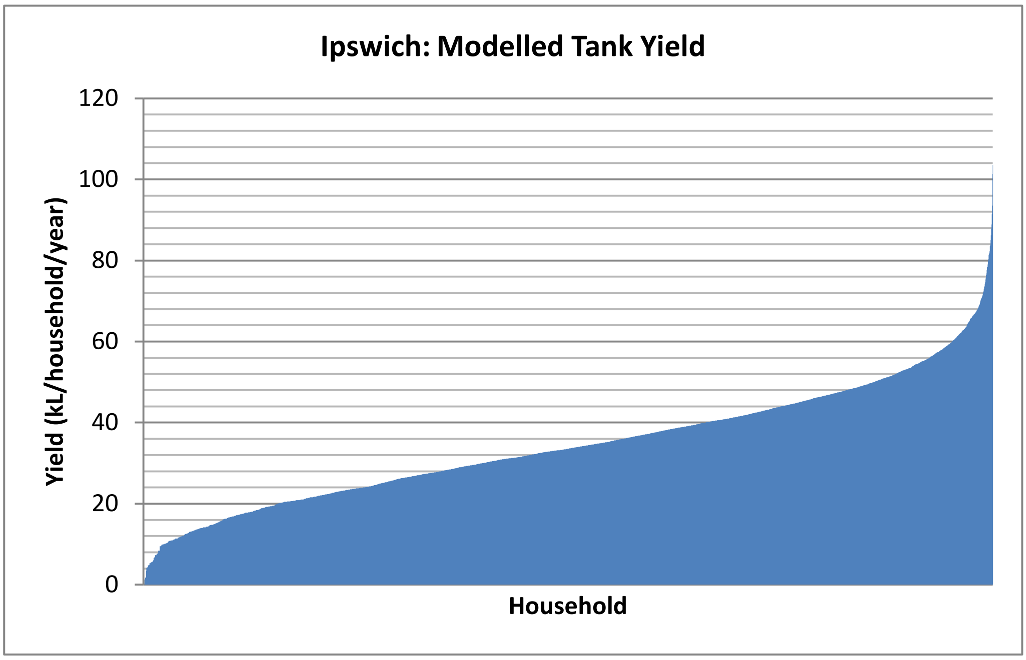


Figure 69. Ipswich: 10,000 tank yield values, generated from stochastic simulation.

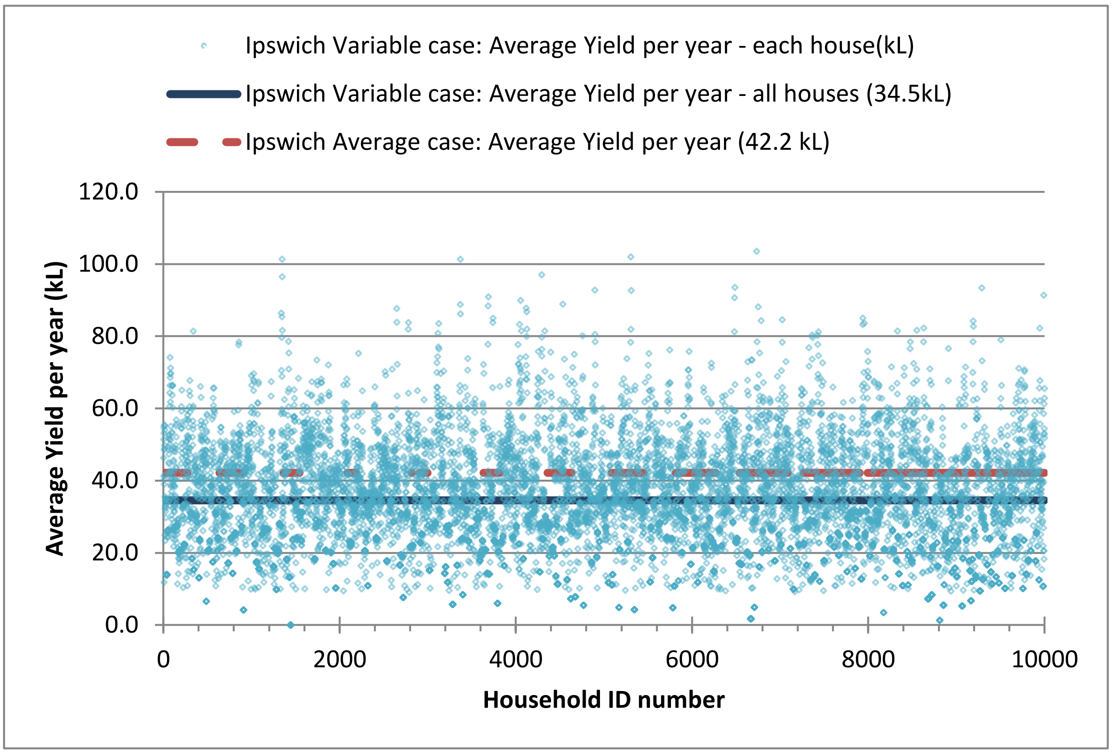
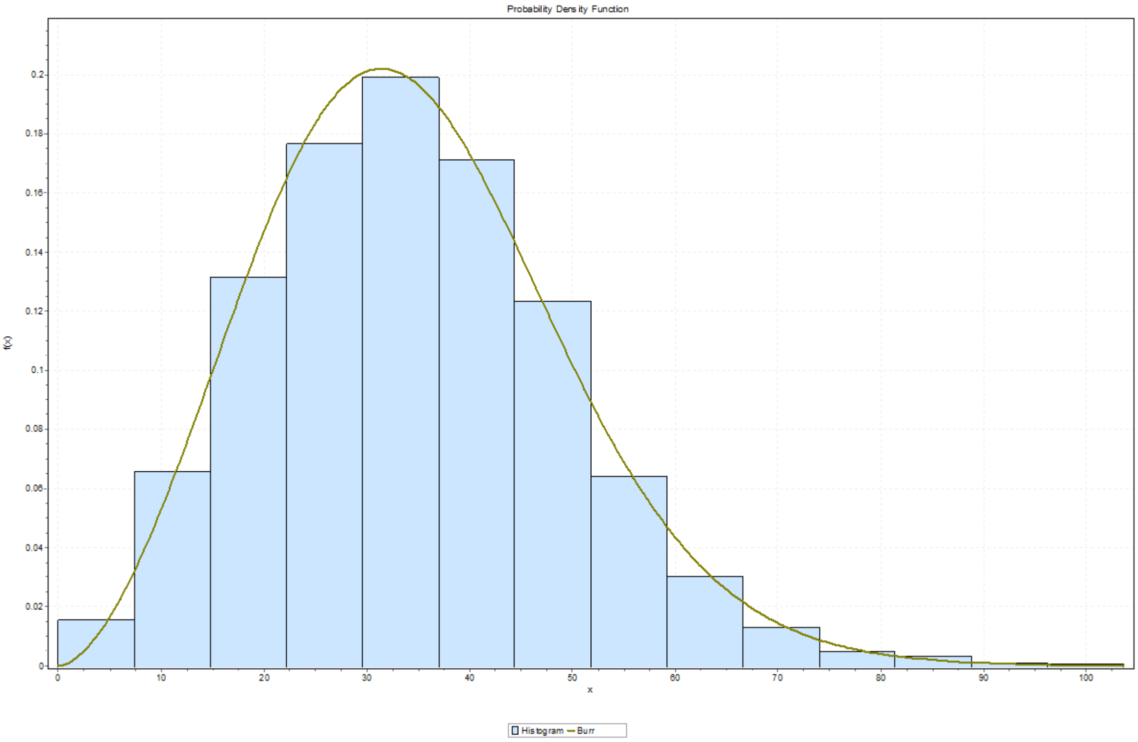


Figure 70. **Ipswich: 10,000 tank yield values generated from stochastic simulation (blue dots), mean of 10,000 tank yields and the tank yield obtained by using average values of tank and water use characteristics.**



Percentile	Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max
Value	0	12.612	16.561	23.73	33.574	43.962	53.327	59.65	103.57

Figure 71. **Ipswich: probability distribution and percentile values of tank yield (X axis represents tank yield in kL/household).**

Burr distribution was the best-fit probability distribution function to the modelled tank yields in Ipswich (Kolmogorov-Smirnov statistic and P-value = 0.01114, 0.17, respectively; Chi-Squared statistic, DF and P-value = 43.798, 13, 0, respectively; see Appendix B for details). The 50th percentile tank yield was 33.57 kL/hh/yr (i.e. of the 10,000 tank yield values, 5,000 values were below 33.57 kL/hh/yr). Since the distribution of tank yield was not symmetrical (Figure 71), the median value was used to report the tank yield in absolute terms.

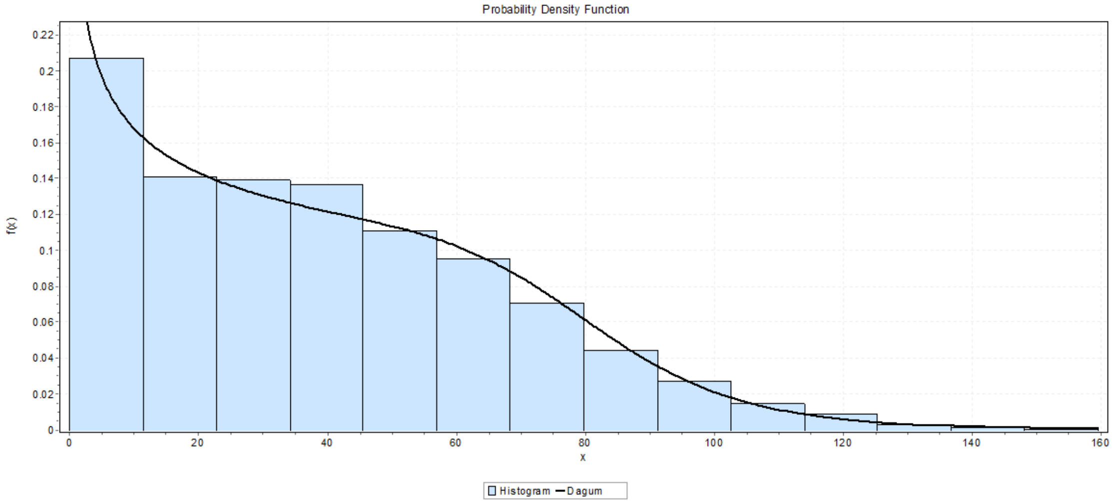
3.6.4.2. Tank Overflow

The mean of 10,000 tank overflow values was 39.16 kL/hh/yr with a standard deviation of 29.05 kL/household/year (see Appendix C for descriptive statistics).

The average case found the overflow of 31.40 kL/hh/yr. This was a 20% percent underestimation of overflow when compared to the mean of the variable case.

The 10,000 tank overflow values in kL/hh/yr were fitted to a set of theoretical distribution functions using Easy Fit Professional (2010). Dagum distribution was the best-fit probability distribution function to the modelled tank overflow in Ipswich (Kolmogorov-Smirnov statistic and P-value = 0.0211, 0, respectively; see Appendix C for details). As shown in Figure 72, the distribution was not symmetrical, which indicated that 50th percentile value was appropriate to report the tank overflow in absolute terms. The 50th percentile value of the tank overflow was 35.27 kL/hh/yr.

Since the stochastic simulation was carried out on a daily basis, for absolute values of overflow, the overflow value obtained with daily simulations must be corrected by considering the results reported in Table 12 (i.e. the tank overflow obtained with daily simulation was about 30% more than the tank overflow obtained with hourly simulation). By accounting for the error caused by daily simulation, the expected tank overflow for Ipswich LGA was 27.13 kL/hh/yr.



Min	5%	10%	25% (Q1)	50% (Median)	75% (Q3)	90%	95%	Max	Mean	std dev
0.00	0.91	3.72	14.82	35.27	58.88	79.42	92.33	159.52	39.16	29.05

Figure 72. **Ipswich: probability distribution and percentile values of tank overflow (X axis represents tank overflow in kL/hh/yr).**

In summary, for Ipswich LGA, results indicated that:

- The expected tank yield was 33.57 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation;
- The expected overflow was 27.13 kL/hh/yr. This was the median value of 10,000 tank yield values computed through stochastic simulation and corrected to account for the effect of daily simulation; and
- If average values were used for both tank and water use characteristics, the tank yield would be overestimated 22% and the tank overflow would be underestimated by 20%.

4. RESULTS: SUMMARY AND DISCUSSION

Tank yield, tank overflow and water quality implications of a cluster of rainwater tanks were quantified for five LGAs in the SEQ: Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich. The average annual rainfall in these five LGAs during the period of analysis (1 January 1962 to 31 December 2011) varied from 866 mm in Ipswich to 1676 mm in Sunshine Coast. Brisbane, Moreton Bay and Gold Coast exhibited an average annual rainfall of 1129 mm, 1313 mm and 1455 mm. In this chapter, we summarise the results described in the previous chapter.

4.1. Rainwater Tank Yield

Two methods were adopted to quantify the yield from a cluster of rainwater tanks. They were called variable and average methods. The variable method used stochastic simulation whereas the average method used deterministic simulation to study the storage behaviour of a rainwater tank.

In the stochastic simulation, variables that affected the storage behaviour of a rainwater tank were specified as probability distribution functions (see Chapter 1). The probability distributions were derived from the observed data (see Chapter 1). The observed data of the closest LGA was used if the data for a particular LGA was not available. The case that adopted the stochastic simulation approach was called ‘variable case’.

In the deterministic simulation, average values were used for the variables that affected the storage behaviour of a rainwater tank (see Chapter 1). This is generally the commonly adopted method by practitioners to quantify both supply and overflow implications from a cluster of rainwater tanks. The case that adopted the deterministic simulation approach was called ‘average case’.

Table 35. **All LGAs: the yield expected from a cluster rainwater tanks, with and without considering the spatial variability of tank and water use characteristics.**

LGA	Average annual rainfall over 1962-2011 (50 years)	Tank Yield (kL/household/year)			The mean demand placed on the tank in kL/household/year	Volumetric reliability, in relation to 50th percential yield	Overestimation of tank yield if spatial variability ignored
		If spatial variability ignored	If spatial variability is included: mean value	If the spatial variability is included: 50th percentile value			
Brisbane	1129	50.13	43.37	42.26	62.42	68%	16%
Moreton Bay	1313	50.32	43.9	42.92	62.45	69%	15%
Sunshine Coast	1676	57.08	50.25	47.81	64.81	74%	14%
Ipswich	866	42.19	34.53	33.57	48.3	70%	22%
Gold Coast	1455	49.03	44.38	43.66	54.69	80%	10%
Average of five LGAs (SEQ)	**1287.80**	**49.75**	**43.29**	**42.04**	**58.53**	**72%**	**15%**

The tank yields obtained for the variable and average cases were different (Figure 73), and on average over the yield values obtained for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich for the average case showed a 15% overestimation compared to the variable case yield (Figure 73). For individual LGAs, the overestimation errors were: 16% for Brisbane, 15% for Moreton Bay, 14% for Sunshine Coast, 22% for Ipswich and 10% for Gold Coast (Table 35).

The yield and the volumetric reliability expected from a cluster of rainwater tanks, spatial variability exhibited by the tank sizes and roof areas and the error caused by not considering of the spatial variability for all the LGA considered in the study are summarised in Table 35.

The expected tank yield values to be used for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich for TWCM planning studies are listed in Table 37 in terms of kL/hh/yr and L/p/d. The conversion used 2.6 persons/household and 365.25 days/year. Also shown in Table 37 is the amount of spatial variability to be expected for the tank yield in each of the LGA, along with the observed residential water consumption.

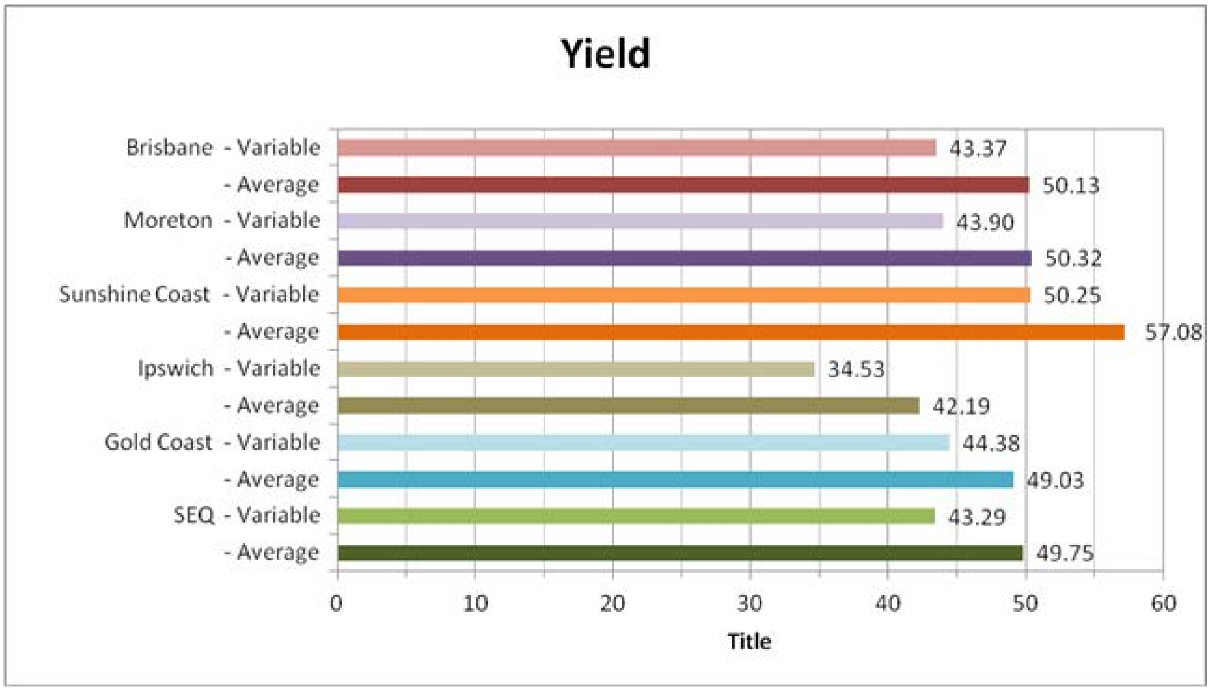


Figure 73. All LGAs: A comparison tank yield values (in kL/hh/yr) obtained for variable and average cases.

Table 36. All LGAs: Observed tank sizes (i.e. effective volumes) and connected roof areas: mean, standard deviation and coefficient of variation.

LGA	Variability exibited by observed tank size (kL)			Variability exibited by observed roof area (m^2)		
	mean	Standard deviation	coefficient of variation	Mean	Standard deviation	coefficient of variation
Brisbane	4.4	2.69	61%	111.63	47.14	42%
Moreton Bay	5.54	1.59	29%	102.07	46.8	46%
Sunshine Coast	5.63	4.6	82%	102.07	46.8	46%
Ipswich	6.67	4.19	63%	102.07	46.8	46%
Gold Coast	5.61	0.86	15%	97.61	44.22	45%
Average of five LGAs (SEQ)	**5.57**	**2.79**	50%	**103.09**	**46.35**	45%

The following key points can be observed from the results:

1. The observed data on tank sizes exhibited a variation across and within the LGAs. The mean observed tank sizes were 4.4 kL, 5.54 kL, 5.63 kL, 5.61 kL and 6.67 kL, respectively for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich. The coefficient of variation of the tank sizes were: 61%, 29%, 82%, 15% and 63% respectively for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich (Table 36).

2. The observed data on roof areas connected to the tank exhibited a variation across and within the LGAs. The mean observed roof areas connected to the tank were: 116.6 m^2 for Brisbane, 102.07 m^2 for Moreton Bay and 97.61 m^2 for Gold Coast. The coefficient of variation of the connected roof areas were: 42% for Brisbane, 46% for Moreton Bay and 45% for Gold Coast (Table 36). Roof area data were not available for Sunshine Coast and Ipswich. The roof area data of Moreton Bay was assumed to be applicable to both Sunshine Coast and Ipswich.

3. It was not appropriate to quantify yield from a large number of rainwater tanks spread across an area, e.g. suburb, LGA or SEQ, using average values for tank sizes, connected roof areas and water use, because these factors can vary spatially (as shown in #1 and #2 above). Some factors such as water consumption vary temporally, too, due to individual water use behaviours influenced by the climatic factors such as rainfall and daily temperature.

4. Using the stochastic simulation approach, we showed that if the spatial variability was ignored, errors could be introduced, for both water quantity and quality implications of a large number of rainwater tanks spread across an area. The errors introduced to tank yield varied from 10% overestimation in Gold Coast to 22% overestimation in Ipswich, with a mean error of 15% overestimation over the five LGAs considered in the study, compared to the tank yield obtained by considering the spatial variability of tank sizes, connected roof areas and water use (Table 35).

5. The expected yield from the rainwater tanks varied across the SEQ. The tank yield in kL/hh/yr for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich were 42.26, 42.92, 47.81, 43.66 and 33.57, respectively (Table 35). These values represented the 50th percentile of 10,000 probable tank yield values obtained from stochastic simulation.

6. Given the variation in rainfall, it was not appropriate to use the average value of tank yield as a generalised value for the SEQ region. However, if a value was needed for the tank yield in SEQ, particularly for urban water planning studies, it would be reasonable to use the average value of all the yield figures reported in the study, i.e. 42 kL/hh/yr or 44 L/p/d. This was because the LGAs considered for the study were located in the north, south, east and west of the SEQ region, and in terms of water use, these LGAs showed a representative variation across the SEQ (Beal and Stewart, 2011).

7. If rainwater was used for the toilet use, laundry and garden, rainwater could meet about 72% of the demand placed on the tank on average, i.e. the average volumetric reliability. This was the average of 68%, 69%, 74%, 80% and 70% volumetric reliability found, for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich, respectively (Table 35).

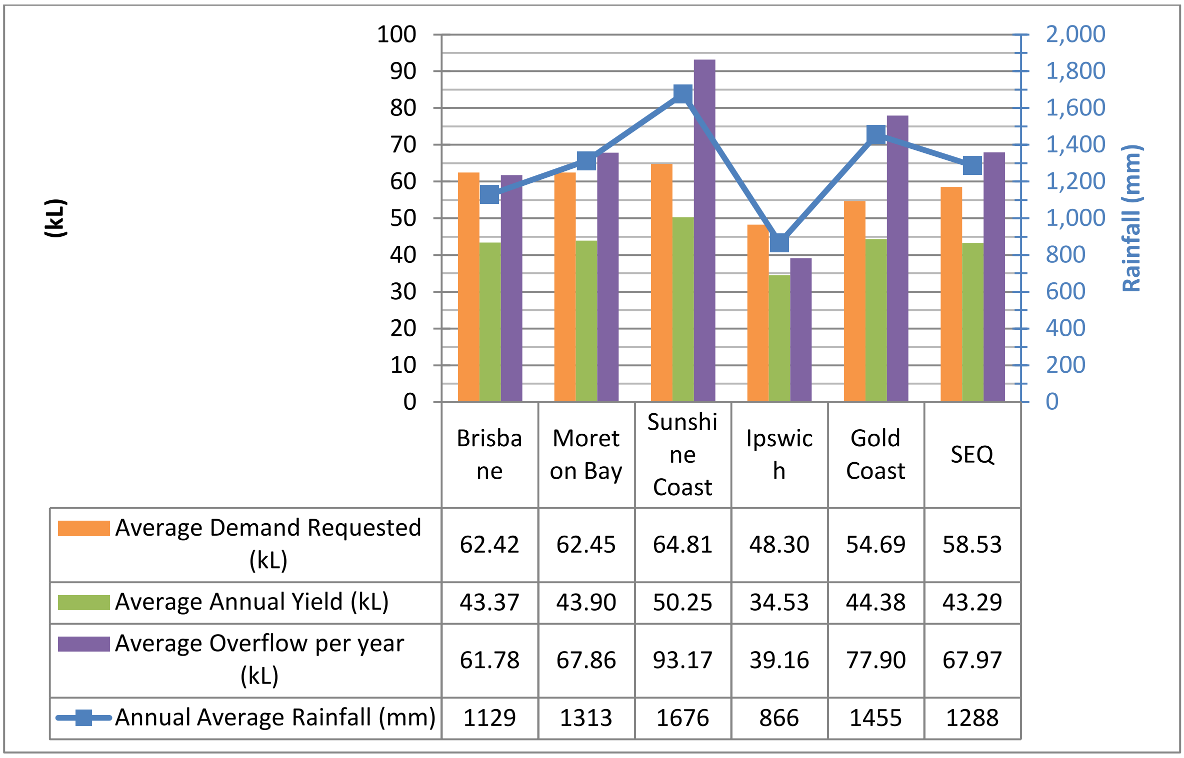
8. Rainwater tanks could supply about 33% of the total household water consumption in the SEQ region. This was the average of 34%, 35%, 32%, 31% and 32%, found for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich, respectively (Table 37).

9. Higher tank yields were observed for areas where the rainfall was higher (see Figure 74, which shows mean modelled tank yield, tank overflow, and the demand placed on the tank against the average annual rainfall). Of all the LGAs analysed, Sunshine Coast had the highest tank yield (the mean was 50.25 kL/hh/yr and the 50th percentile value was 47.81 kL/hh/yr) and the highest annual rainfall (1676 mm), and Ipswich had the lowest tank yield (the mean was 34.53 kL/hh/yr and the 50th percentile value was 33.57 kL/hh/yr) and the lowest average annual rainfall (866 mm).

10. A considerable variation could be expected within a LGA, for the yield of individual tanks. The expected ranges obtained through stochastic simulation were: 4-117 kL/hh/yr in Brisbane, 4-125 kL/hh/yr in Moreton Bay, 15-154 kL/hh/yr in Sunshine Coast, 5-107 kL/hh/yr in Gold Coast and 0-104 kL/hh/yr in Ipswich (Table 37). The average range over five LGAs was: 6-121 kL/hh/yr (Table 37).

Table 37. **All LGAs: the expected rainwater tank yield and the probable variability expected for tank yields.**

LGA	Brisbane	Moreton Bay	Sunshine Coast	Ipswich	Gold Coast	Average for SEQ
Tank yield in kL/household/year (50th percentile value)	42.26	42.92	47.81	33.57	43.66	42.04
Tank yield in l/p/d	44.50	45.20	50.34	35.35	45.97	44.27
Modelled variability in tank yield kL/household/year	4.64 - 116.83	4.64 - 125.36	15.72 - 154.13	5.43 - 103.61	0 -103.57	6.09 -120.7
Observed water use in l/p/d (without leaks)	130.4	130.4	156.7	108.9	149.96	135.27
Percentage of water consumption met by the tank	34%	35%	32%	32%	31%	33%



	Brisbane	Moreton Bay	Sunshine Coast	Ipswich	Gold Coast	SEQ
🟧 Average Demand Requested (kL)	62.42	62.45	64.81	48.30	54.69	58.53
🟩 Average Annual Yield (kL)	43.37	43.90	50.25	34.53	44.38	43.29
🟪 Average Overflow per year (kL)	61.78	67.86	93.17	39.16	77.90	67.97
■ Annual Average Rainfall (mm)	1129	1313	1676	866	1455	1288

Figure 74. **All LGAs: Average annual Rainfall, demand requested, yield and overflow for SEQ regions.**

It was important to note that the tank yield figures of our study were in the same order of magnitude when compared with tank yield studies conducted in SEQ by Beal *et al*. (2012), Chong *et al*. (2011), Umapathi *et al*. (2012) and QWC (2011) (Table 38). Therefore, it could be said that even though we did not compare the validity of the tank yield values computed from the stochastic simulation approach using the observed data of tank supplies (simply because of the lack of observed data), the tank yield figures found from our study were of similar magnitude to those reported in the past studies conducted in SEQ. This provided a quasi-validation to the tank yield figures obtained from the stochastic simulation. However, we recommend that a field study be undertaken as part of future research activities, to measure tank supplies in at least one of the LGAs considered in this study, in order to provide data to validate the stochastic simulation approach.

Table 38. Rainwater tank yield studies conducted in SEQ.

Study	**Beal *et al*. (2012)**	**Chong *et al*. (2011)**	**Umapathi *et al*. (2012)**	**QWC (2011)**	**This study (based on the average of all five LGAs)**
Based on	2008 metered consumption data	2008 and 2009 metered consumption data	2010 metered consumption data	2011 metered consumption data	2010 winter end use data sourced from Beal and Stewart (2012)
Average consumption during the study period in kL/hh/yr	163	145	153	158	138
Rainwater tank yield in kL/hh/yr	50	58	40	37	42

4.2. Rainwater Tank Overflow and Associated Water Quality

Similar to tank yields, tank overflows were quantified through the behavioural analysis of the tank storage. To study water quality implications associated with the overflow, nutrient and sediment mixing behaviour in a tank was examined.

The following key points could be observed from the results related to the tank overflow calculation:

1. The hourly time-step would be desirable over the daily time-step of simulation for the studies on tank overflow and associated water quality parameters such as TP, TN and TSS. The magnitude of the error introduced to the overflow volume of water due to the use of daily time-step of simulation was in the order of 30% overestimation, compared to the overflow computed using hourly simulation. The study used daily simulation time step on the basis that the error introduced by the daily simulation to the tank yield was insignificant (i.e. only 2% difference in tank yield between the daily and hourly simulation), and that the quantification of the error introduced due to ignoring of the spatial variability of tank and water use characteristics was performed on relative terms. The overflows were corrected to account for the error introduced due to daily simulation, in order to present overflow results in absolute terms.
2. The overflow from the rainwater tanks varied across the SEQ. For Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich, the expected values for overflows are 44.38, 48.88, 68.04, 57.01 and 27.13 kL/hh/yr, respectively (Table 39 and Figure 75). These were the 50th percentile values obtained with stochastic simulation, corrected for hourly simulation time-step.
3. The tank sizes and roof areas varied across the LGAs (i.e. points #1 and #2 under section 4.1). If the spatial variability present in tank sizes, connected roof areas and water use were ignored, errors could be introduced to the collective overflow from a large number of rainwater tanks spread across an area. The error introduced to tank overflow varied from 6% underestimation in Gold Coast to 20% underestimation in Ipswich, with a mean error of 11% underestimation, compared to the tank overflow obtained by considering the spatial variability of tank sizes, connected roof areas and water use (Table 39).
4. Like tank yields, given the variation in rainfall, it was not appropriate to use the average value of tank overflow as a generalised value for the SEQ. However, if a value was needed for the tank overflow in SEQ, particularly for urban water planning studies, 49 kL/hh/yr could be used as a typical tank overflow in SEQ, but it should not be used for any detailed catchment modelling studies.
5. The study examined nutrients (TP and TN) and sediments (TSS) associated with the overflow, in particular the effect of using average values for tank sizes, roof areas, water use and inflow concentrations of TP, TN and TSS on the concentrations of TP, TN and TSS associated with the outflow. However, there was a lack of SEQ based data to examine water quality implications. Hence, we used the data available in literature sources. Therefore, the results on TP, TN and TSS should be considered as indicative only for SEQ.

6. The analysis based on the data on TP, TN and TSS sourced from the literature indicated that ignoring the spatial variability present in tank sizes, roof areas, water loss from rooves, inflow concentrations of TP, TN and TSS into the tank and the demand placed on the tank, could introduce errors to the quality of overflow water to stormwater. The magnitude of the error for loads associated with the overflow was: 17% underestimation for TSS, 22% underestimation for TP and 15% underestimation for TN, compared to a case that considered the spatial variability of the above mentioned factors.

Table 39. **All LGAs: the overflow expected from a cluster rainwater tanks.**

LGA	Average annual rainfall over 1962-2011 (50 years)	Tank overflow (kL/household/year)			The mean demand placed on the tank in kL/household/year	Overestimation of tank overflow if spatial variability ignored
		If spatial variability ignored (with daily simulation)	If spatial variability is included: mean value (with daily simulation)	If the spatial variability is included: 50th percentile value and corrected for daily simulation		
Brisbane	1129	54.90	61.78	44.38	62.42	-11%
Moreton Bay	1313	61.32	67.86	48.88	62.45	-10%
Sunshine Coast	1676	86.14	93.17	68.04	64.81	-8%
Ipswich	866	31.40	39.16	27.13	48.30	-20%
Gold Coast	1455	73.06	77.90	57.01	54.69	-6%
Average of five LGAs (SEQ)	**1287.8**	**61.36**	**67.97**	**49.09**	**58.53**	**-11%**

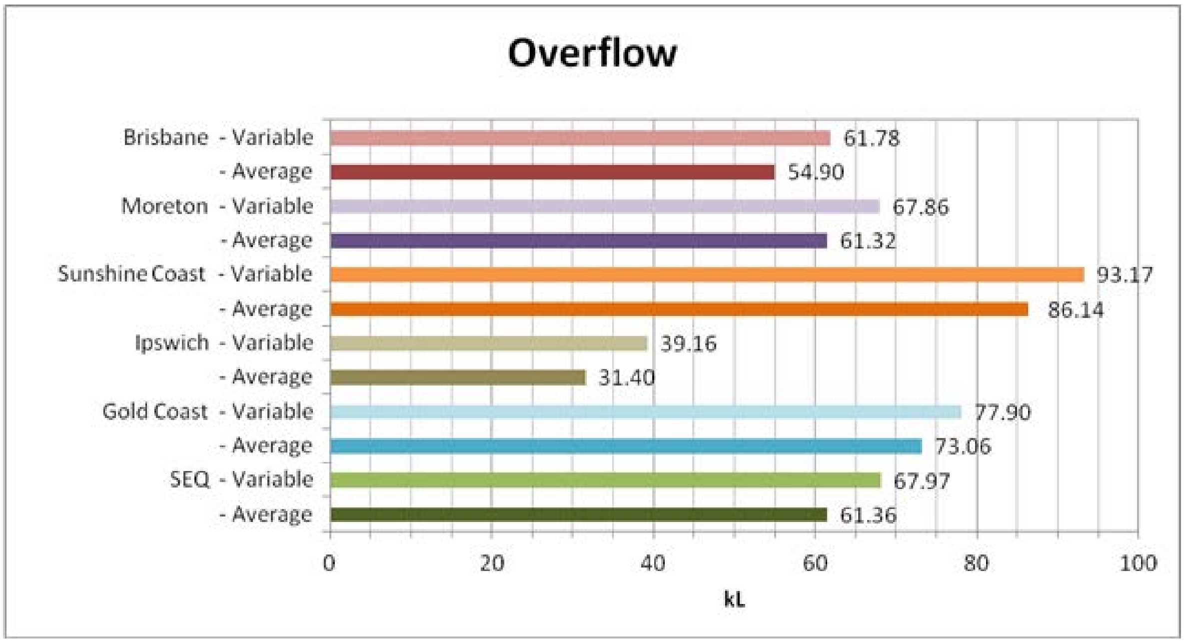


Figure 75. **All LGAs: A comparison of rainwater tank overflow in kL/hh/yr.**

5. CONCLUSIONS

This study quantified the expected yield and overflow from a cluster of household rainwater tanks in the SEQ, by focussing on five LGAs: Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich. In addition, TP, TN and TSS loads associated with the overflow, from a cluster of household rainwater were examined, but the required data was not available to quantify TP, TN and TSS loads associated with the overflow for the LGAs considered. Hence, we used literature-based data to examine the water quality implications.

The conclusions of the study were:

1. The observed data on tank sizes exhibited a variation across and within the LGAs. The mean observed tank sizes for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich were 4.4 kL, 5.54 kL, 5.63 kL, 5.61 kL and 6.67 kL, respectively. The coefficient of variation of the tank sizes were: 61%, 29%, 82%, 15% and 63% respectively for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich.
2. The observed data on roof areas connected to the tank exhibited a variation across and within the LGAs. The mean observed roof areas connected to the tank were: 116.6 m^2 for Brisbane, 102.07 m^2 for Moreton Bay and 97.61 m^2 for Gold Coast. The coefficient of variation of the connected roof areas were: 42% for Brisbane, 46% for Moreton Bay and 45% for Gold Coast. Roof area data were not available for Sunshine Coast and Ipswich. The roof area data of Moreton Bay was assumed to be applicable to both Sunshine Coast and Ipswich.
3. The observed data on household end uses exhibited a variation across and within the LGAs as well. The observed totals of household water consumption (without leaks) were: 130 L/p/d (litres per person per day) in Brisbane, 157 L/p/d in Sunshine Coast, 138 L/p/d in Gold Coast and 109 L/p/d in Ipswich.
4. Using the stochastic simulation approach, we showed that if the spatial variability was ignored, errors could be introduced, for both water quantity and quality implications of a large number of rainwater tanks spread across an area. The errors introduced to tank yield varied from 10% overestimation in Gold Coast to 22% overestimation in Ipswich, with a mean error of 15% overestimation over the five LGAs considered in the study, compared to the tank yield obtained by considering the spatial variability of tank sizes, connected roof areas and water use. Similarly, the errors introduced to tank overflow varied from 6% underestimation in Gold Coast to 20% underestimation in Ipswich, with a mean error of 11% underestimation over the five LGAs considered in the study, compared to the tank overflow obtained by considering the spatial variability of tank sizes, connected roof areas and water use.
5. A sensitivity analysis was conducted to understand the sensitivity of the spatial variability exhibited by each input variable of the rainwater tank simulation on the tank yield and overflow. Spatial variability of the demand placed on the rainwater tank was the most sensitive parameter to both tank yield and overflow. For example, the overestimation error associated with Brisbane's tank yield was 16%, which could be reduced to 6% by considering the spatial variability of demand alone. Considering the variability in roof areas alone could reduce the overestimation of tank yield to 11% and that considering the variability in tank sizes alone could reduce the overestimation of tank yield to 14%. For the accurate and robust prediction of the supply and overflow from a cluster of rainwater tanks, these results implied the need for predicting the household end use, as accurately as possible, and the need for considering the spatial and temporal variability of household water use.
6. The expected yield from domestic rainwater tanks varied across SEQ. The tank yield expected for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich were 42, 43, 48, 44 and 34 kL/hh/yr, respectively. Each of the tank yield values represented the 50th percentile (or median) value of 10,000 tank yield values obtained through stochastic simulation of the tank storage over a 50-year period. The average tank yield across SEQ region based on the tank yields of the five LGAs was 42 kL/hh/yr (or 44 L/p/d).

7. The tank yields of this study were in the same order of magnitude when compared with tank yield studies conducted in SEQ by Beal *et al*. (2012), Chong *et al*. (2011), Umapathi *et al*. (2012) and QWC (2011). The tank yields reported in these studies were: 50 kL/hh/yr, 58 kL/hh/yr, 40 kL/hh/yr and 37 kL/hh/yr, respectively, which provided some validity to the yield estimates found through stochastic simulation. It should be noted that observed data was not available to compare tank yields obtained through stochastic simulation.
8. A considerable variation could be expected for the yields of individual tanks in a cluster of tanks spread across an area, which could be a suburb, a LGA or a region. The expected ranges for tank yields obtained through stochastic simulation were: 4-117 kL/hh/yr in Brisbane, 4-125 kL/hh/yr in Moreton Bay, 15-154 kL/hh/yr in Sunshine Coast, 5-107 kL/hh/yr in Gold Coast and 0-104 kL/hh/yr in Ipswich. The average range over five LGAs was: 6-121 kL/hh/yr.
9. The expected overflow from the domestic rainwater tanks varied across SEQ. For Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich, the expected values for overflows were 44, 49, 68, 57 and 27 kL/hh/yr, respectively. The average tank overflow based on the tank overflows of five LGAs was 49 kL/hh/yr.
10. If rainwater was used for toilet use, clothes washing and garden use, rainwater can meet about 72% of the demand placed on the tank. This was the average 68%, 69%, 74%, 80% and 70% found for Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich, respectively.
11. The water quality analysis based on the data on TP, TN and TSS sourced from the literature indicated that ignoring the spatial variability present in tank sizes, roof areas, losses from the roof, inflow concentrations of TP, TN and TSS into the tank and the demand placed on the tank, could introduce errors to the quality of overflow water. The magnitudes of the error for the loads associated with the overflow were: 9% underestimation for TSS, 9% underestimation for TP and 11% underestimation for TN, compared to a case that considered the spatial variability of the above mentioned factors. Unlike, the tank yield and tank overflow results, the results related to TP, TN and TSS should be used cautiously because they were based on the data available in the literature.
12. As expected, rainfall showed a positive correlation with both tank yield and tank overflow, i.e. higher the rainfall, higher the tank yield and overflow.
13. When using the stochastic simulation approach, care should be taken on the time-step of simulation and the number of iterations of the stochastic simulation. Hourly time-step of simulation would be desirable over a daily time-step. However, for yield studies, comparable results to hourly time-step simulation could be obtained by undertaking behavioural simulation of tank storage on a daily basis. It was found that the tank yield obtained with daily simulation was about 2% more than the yield obtained with hourly simulation. Hence, we used a daily time-step for this study. The number of iterations required for the stochastic simulation could vary depending on the probability distributions used for input variables. Through trialling of different number of iterations, 10,000 iterations were found to be sufficient to ensure adequate sampling from the probability distributions of the input variables.

The results of the study can be used to inform the development of TWCM plans in Brisbane, Moreton Bay, Sunshine Coast, Gold Coast and Ipswich local government areas, and the strategic water supply planning in SEQ, in terms of the amount of grid water saved by the use of rainwater tanks and the amount of overflow expected to occur from the rainwater tanks. For the areas in SEQ not included in the present study, the error values provided for yield and overflow may be used to correct the yield and overflow values obtained with deterministic simulation of rainwater tanks. Deterministic simulation is easy to conduct because it simply uses the average values for tank sizes, connected roof areas, roof losses and the demand. However, it is important to note that the error values are not generic and that they vary depending on the climate, tank characteristics and the water use characteristics. For water quality implications, the error values given in the report should be used cautiously, because they are based on the data sourced from the literature.

Organisations interested in applying the stochastic simulation methodology for rainwater tanks may use the rainwater tank model and the stochastic demand generator model used in this study. The stochastic demand generator model is available through eWater CRC's Urban Developer model (http://www.ewater.com.au/). The rainwater tank model has also been developed as part of eWater CRC. Hence, a copy of this model may be obtained by contacting eWater Limited (http://www.ewater.com.au/).

Results presented in the report can be enhanced by improving the limitations present in both the rainwater tank model and the stochastic demand generator model, and by using an adequate and representative data samples to derive probabilities. In regard to the models, the key limitation is not being able to assign any type of probability distribution (either theoretical or the observed) to input variables of both models. In regard to the data, the key limitation is the unavailability of data that can adequately represent the area being considered. This study has used the most up to date data, but the sample sizes are less than 100 data points in most cases, which is not adequate for an area of about 22,000 km^2.

APPENDIX A: Fitting Probability Distributions to Observed Tank Sizes and Roof Areas

Brisbane Tank Sizes

Descriptive Statistics (note: tank sizes are in litres):

Statistic	Value
Sample Size	5008
Range	27891.0
Mean	4399.0
Variance	7.2413E+6
Std. Deviation	2691.0
Coef. of Variation	0.61172
Std. Error	38.026
Skewness	3.7279
Excess Kurtosis	19.196

Percentile	Value
Min	2664.8
5%	2664.8
10%	2664.8
25% (Q1)	2664.8
50% (Median)	4441.3
75% (Q3)	4441.3
90%	6661.9
95%	8882.6
Max	30556.0

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
4	Cauchy	0.2059	1	312.29	1	10433.0	13
36	Log-Logistic	0.21443	2	331.69	2	8040.9	7
35	Log-Gamma	0.22036	3	340.51	4	7866.1	5
40	Lognormal	0.22088	4	347.12	5	8044.1	8
14	Fatigue Life	0.22361	5	366.16	9	10174.0	12
16	Frechet	0.22811	6	332.01	3	8114.5	9
47	Pearson 6	0.23706	7	348.39	6	10556.0	16
45	Pearson 5	0.23774	8	349.39	7	10554.0	15
21	Gen. Gamma	0.24133	9	405.45	11	10161.0	11
38	Log-Pearson 3	0.24155	10	360.55	8	10930.0	23
52	Rayleigh	0.25039	11	447.77	15	11006.0	25
37	Log-Logistic (3P)	0.2626	12	6050.6	37	N/A	
60	Weibull	0.26968	13	503.38	22	10719.0	17
24	Gen. Pareto	0.27244	14	428.53	12	10787.0	22
23	Gen. Logistic	0.27368	15	442.36	14	10740.0	18
55	Rice	0.2741	16	487.53	20	7909.7	6
20	Gen. Extreme Value	0.27706	17	451.85	17	10768.0	21
25	Gumbel Max	0.27715	18	432.59	13	11008.0	26
32	Laplace	0.27862	19	472.87	18	10755.0	19
10	Error	0.27862	20	472.87	19	10755.0	20

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
28	Inv. Gaussian	0.28179	21	399.58	10	11469.0	29
27	Hypersecant	0.28757	22	498.67	21	8139.9	10
39	Logistic	0.28983	23	517.74	23	10484.0	14
42	Normal	0.29248	24	577.34	24	11162.0	27
18	Gamma	0.29333	25	449.8	16	11214.0	28
48	Pearson 6 (4P)	0.30779	26	7103.4	42	N/A	
53	Rayleigh (2P)	0.31021	27	601.77	25	7864.7	4
58	Uniform	0.31396	28	1310.6	32	N/A	
41	Lognormal (3P)	0.32842	29	5923.5	36	N/A	
26	Gumbel Min	0.362	30	1092.7	29	N/A	
15	Fatigue Life (3P)	0.37007	31	1470.6	33	13940.0	32
61	Weibull (3P)	0.3746	32	6166.3	38	N/A	
51	Power Function	0.37996	33	8218.6	44	N/A	
19	Gamma (3P)	0.39171	34	7858.9	43	N/A	
22	Gen. Gamma (4P)	0.39557	35	11747.0	50	15525.0	35
43	Pareto	0.39557	36	820.76	26	15743.0	37
13	Exponential (2P)	0.39574	37	1043.9	28	15682.0	36
30	Johnson SB	0.39772	38	7049.1	41	N/A	
3	Burr (4P)	0.39875	39	8633.9	46	N/A	
1	Beta	0.42464	40	9047.1	47	N/A	
8	Dagum (4P)	0.4347	41	9758.6	49	N/A	
5	Chi-Squared	0.44006	42	2.1488E+5	58	11000.0	24
12	Exponential	0.45434	43	943.61	27	14792.0	33
33	Levy	0.46748	44	1651.4	34	20657.0	41
9	Erlang	0.48113	45	1146.8	31	11815.0	30
44	Pareto 2	0.50049	46	1145.2	30	15375.0	34
49	Pert	0.53746	47	19162.0	54	16479.0	38
17	Frechet (3P)	0.58628	48	8226.0	45	6346.8	3
46	Pearson 5 (3P)	0.58831	49	6960.2	40	2311.5	2
54	Reciprocal	0.59441	50	18930.0	53	16748.0	39
6	Chi-Squared (2P)	0.60095	51	70124.0	56	12287.0	31
34	Levy (2P)	0.60194	52	13670.0	51	1982.5	1
29	Inv. Gaussian (3P)	0.604	53	18107.0	52	N/A	
57	Triangular	0.69266	54	9752.8	48	18134.0	40

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
7	Dagum	0.78026	55	4766.8	35	45902.0	43
31	Kumaraswamy	0.7919	56	24880.0	55	42736.0	42
11	Error Function	0.83898	57	6864.7	39	62268.0	44
56	Student's t	1.0	58	79272.0	57	1.4339E+11	45
2	Burr	N/A		N/A		N/A	
50	Phased Bi-Exponential	N/A		N/A		N/A	
59	Wakeby	N/A		N/A		N/A	
62	Erlang (3P)	No fit					
63	Johnson SU	No fit					
64	Nakagami	No fit					
65	Phased Bi-Weibull	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Note: ‘yes’ indicates that the distribution is not a good fit to the data at significant level ‘a’, i.e. the null hypothesis that the data conform to the specified distribution should be rejected at the specified significant level . Different levels of significance are shown. The commonly used significant level is 0.05. If the result given is ‘no’, it indicates that the null hypothesis should NOT be rejected, i.e. data conform to the specified distribution at the specified significant level.

The results in the table below indicates that even though Cauchy distribution is the rank #1 distribution, it is not acceptable at 0.05 significant level (and also, even at 0.01 significant level).

Therefore, it is important to note that in this report context, ‘best-fit’ distribution does not mean that the distribution is statistically acceptable. The Goodness of Fit results should be used to examine the acceptability of the fitted distribution. For cases, where the best-fit distribution is not statistically acceptable (such as the data on Brisbane tank sizes), it may be appropriate to use the observed distribution, instead of using a theoretical distribution.

This note is applicable to all the results given in Appendix A, B and C.

Cauchy [#4]					
Kolmogorov-Smirnov					
Sample Size	5008				
Statistic	0.2059				
P-Value	0				
Rank	1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01516	0.01728	0.01919	0.02145	0.02302
Reject?	Yes	Yes	Yes	Yes	Yes
Anderson-Darling					
Sample Size	5008				
Statistic	312.29				
Rank	1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom	11				
Statistic	10433.0				
P-Value	0				
Rank	13				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	14.631	17.275	19.675	22.618	24.725
Reject?	Yes	Yes	Yes	Yes	Yes

Normal [#42]					
Kolmogorov-Smirnov					
Sample Size	5008				
Statistic	0.29248				
P-Value	0				
Rank	24				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01516	0.01728	0.01919	0.02145	0.02302
Reject?	Yes	Yes	Yes	Yes	Yes
Anderson-Darling					
Sample Size	5008				
Statistic	577.34				
Rank	24				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom	12				
Statistic	11162.0				
P-Value	0				
Rank	27				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	15.812	18.549	21.026	24.054	26.217
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters for the Best-Fit Normal Distributions:

#	**Distribution**	**Parameters**
4	Cauchy	s=960.25 m=3958.1
42	Normal	s=2691.0 m=4399.0

Summary:

The observed tank sizes were not normally distributed (n = 5008; Kolmogorov-Smirnov statistic and P-value = 0.29248, 0 respectively; Chi-Squared statistic, DF and P-value = 11162.0, 12, 0 respectively).

Brisbane Roof Areas

Descriptive Statistics (note roof sizes are in m^2):

Statistic	Value
Sample Size	30
Range	235
Mean	111.63
Variance	2222.2
Std. Deviation	47.141
Coef. of Variation	0.42228
Std. Error	8.6067
Skewness	0.953
Excess Kurtosis	2.7075

Percentile	Value
Min	25
5%	31.6
10%	46.5
25% (Q1)	90.75
50% (Median)	111
75% (Q3)	130
90%	171.9
95%	229.75
Max	260

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
62	Wakeby	0.07666	1	0.17279	1	0.61701	24
4	Cauchy	0.09108	2	0.28828	3	0.98578	26
33	Laplace	0.12152	3	0.28644	2	0.14032	2
11	Error	0.12559	4	0.30155	4	0.14103	3
38	Log-Logistic (3P)	0.12591	5	0.43408	5	0.49531	22
7	Dagum	0.12634	6	0.46228	8	0.82619	25
24	Gen. Logistic	0.13149	7	0.4579	7	0.53675	23
2	Burr	0.13957	8	0.62164	11	0.39698	10
31	Johnson SU	0.14031	9	0.58411	10	0.48085	21
50	Pearson 6 (4P)	0.14438	10	0.65588	13	0.45327	15
48	Pearson 5 (3P)	0.1456	11	0.65219	12	0.45155	13
42	Lognormal (3P)	0.14685	12	0.65788	14	0.45269	14
21	Gen. Extreme Value	0.14692	13	0.67345	18	0.43701	12
23	Gen. Gamma (4P)	0.14745	14	0.67976	19	0.45388	16
16	Fatigue Life (3P)	0.14847	15	0.66388	15	0.45482	17
28	Hypersecant	0.14966	16	0.43515	6	1.2159	28
10	Erlang (3P)	0.1498	17	0.67326	17	0.45517	19
20	Gamma (3P)	0.15005	18	0.67315	16	0.4549	18
51	Pert	0.16004	19	2.5305	43	0.34844	9
64	Weibull (3P)	0.16016	20	0.8217	23	0.41266	11
19	Gamma	0.16364	21	0.82584	24	0.28788	5
40	Logistic	0.16367	22	0.56007	9	1.1958	27
26	Gumbel Max	0.1637	23	0.8715	29	0.23011	4
18	Frechet (3P)	0.16554	24	0.84506	26	0.3313	8

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
49	Pearson 6	0.168	25	0.83987	25	0.29093	6
22	Gen. Gamma	0.16934	26	0.84773	27	0.29441	7
6	Chi-Squared (2P)	0.1708	27	0.71433	20	1.6671	32
29	Inv. Gaussian	0.17525	28	1.26	34	0.48029	20
58	Rice	0.17591	29	0.86135	28	1.271	30
25	Gen. Pareto	0.17742	30	8.7264	57	N/A	
63	Weibull	0.17844	31	0.89862	30	1.2368	29
39	Log-Pearson 3	0.17952	32	4.6514	49	N/A	
56	Rayleigh (2P)	0.18127	33	0.93261	31	2.3518	33
44	Normal	0.18174	34	0.80576	22	3.0809	37
30	Inv. Gaussian (3P)	0.18238	35	0.77919	21	1.4925	31
43	Nakagami	0.18792	36	0.99631	32	2.6269	34
1	Beta	0.19791	37	2.8161	45	6.3957	48
55	Rayleigh	0.1998	38	1.3486	35	2.9314	36
41	Lognormal	0.20052	39	1.1995	33	5.0555	45
36	Log-Gamma	0.21478	40	1.4249	37	4.9685	43
15	Fatigue Life	0.21905	41	1.3669	36	5.0627	46
61	Uniform	0.22086	42	8.8648	58	N/A	
60	Triangular	0.22686	43	2.5093	42	9.1103	52
5	Chi-Squared	0.22769	44	16.994	60	7.25	50
27	Gumbel Min	0.2297	45	2.4209	41	8.9816	51
37	Log-Logistic	0.22996	46	1.4295	38	4.6518	41
47	Pearson 5	0.24279	47	1.8277	39	4.5823	40
9	Erlang	0.2719	48	2.1964	40	11.727	53
54	Power Function	0.28264	49	7.3253	54	N/A	
17	Frechet	0.29448	50	2.8128	44	17.075	56
3	Burr (4P)	0.32555	51	3.4171	46	4.7942	42
14	Exponential (2P)	0.32777	52	4.5679	48	4.5598	39
32	Kumaraswamy	0.32862	53	4.2201	47	7.3491E-17	1
57	Reciprocal	0.34699	54	4.863	50	5.0	44
13	Exponential	0.35345	55	5.3272	51	12.399	54
46	Pareto 2	0.35556	56	5.3893	52	12.465	55
35	Levy (2P)	0.39322	57	5.946	53	2.7746	35
45	Pareto	0.39956	58	8.5621	56	6.1824	47
34	Levy	0.468	59	8.3955	55	6.4174	49
52	Phased Bi-Exponential	0.48465	60	17.251	61	30.136	57
8	Dagum (4P)	0.5972	61	19.92	62	49.948	58
53	Phased Bi-Weibull	0.61267	62	11.71	59	3.3333	38
12	Error Function	0.79503	63	80.36	63	320.51	59
59	Student's t	0.9992	64	253.29	64	N/A	
65	Johnson SB	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Wakeby [#62]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	30 0.07666 0.98877 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.19032	0.21756	0.2417	0.27023	0.28987
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	30 0.17279 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	4 0.61701 0.96115 24				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	5.9886	7.7794	9.4877	11.668	13.277
Reject?	No	No	No	No	No

Normal [#44]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	30 0.18174 0.24364 34				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.19032	0.21756	0.2417	0.27023	0.28987
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	30 0.80576 22				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	3 3.0809 0.37931 37				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	4.6416	6.2514	7.8147	9.8374	11.345
Reject?	No	No	No	No	No

Fitting Parameters for the Best-Fit and Normal Distributions:

#	Distribution	Parameters
44	Normal	s=47.141 m=111.63
62	Wakeby	a=567.18 b=5.9473 g=14.404 d=0.39241 x=6.2862

Summary:

The observed roof areas were normally distributed (n = 30; Kolmogorov-Smirnov statistic and P-value = 0.18174, 0.24, respectively; Chi-Squared statistic, DF and P-value = 3.0809, 3, 0.38, respectively).

Moreton Bay Tank Sizes

Descriptive Statistics (note tank sizes are in litres):

Statistic	Value
Sample Size	108
Range	10672.0
Mean	5538.3
Variance	2.5365E+6
Std. Deviation	1592.6
Coef. of Variation	0.28757
Std. Error	153.25
Skewness	1.4924
Excess Kurtosis	5.3688

Percentile	Value
Min	1221.1
5%	3020.0
10%	4272.5
25% (Q1)	4997.7
50% (Median)	5496.7
75% (Q3)	5667.1
90%	6428.5
95%	9484.5
Max	11893.0

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
61	Wakeby	0.09796	1	1.0619	2	24.411	3
4	Cauchy	0.10057	2	0.74825	1	8.2355	1
24	Gen. Logistic	0.16348	3	4.6124	5	29.595	5
38	Log-Logistic (3P)	0.1661	4	4.2214	3	22.495	2
2	Burr	0.16646	5	4.4321	4	26.921	4
21	Gen. Extreme Value	0.16749	6	6.2079	10	36.748	6
31	Johnson SU	0.17703	7	6.0778	8	44.957	7
29	Inv. Gaussian	0.17966	8	7.3613	22	47.284	8
49	Pearson 6	0.17972	9	7.0125	15	55.514	14
25	Gen. Pareto	0.18135	10	34.133	49	N/A	
26	Gumbel Max	0.18392	11	7.1135	17	54.487	12
41	Lognormal	0.18475	12	7.5822	26	52.914	11
9	Erlang	0.18571	13	7.4567	24	59.595	16
36	Log-Gamma	0.18929	14	7.6982	28	58.892	15
37	Log-Logistic	0.19501	15	7.6099	27	62.093	20
15	Fatigue Life	0.19584	16	8.0295	29	61.634	19
19	Gamma	0.19621	17	7.3937	23	86.721	35
22	Gen. Gamma	0.19622	18	7.2467	21	86.693	34

#	**Distribution**	**Kolmogorov Smirnov**		**Anderson Darling**		**Chi-Squared**	
		Statistic	**Rank**	**Statistic**	**Rank**	**Statistic**	**Rank**
57	Rice	0.19629	19	9.0007	32	110.88	38
50	Pearson 6 (4P)	0.19834	20	6.8943	12	86.163	33
48	Pearson 5 (3P)	0.19836	21	6.892	11	86.163	32
10	Erlang (3P)	0.19955	22	7.1554	18	86.13	28
42	Lognormal (3P)	0.20069	23	6.9777	14	86.149	31
16	Fatigue Life (3P)	0.20327	24	7.0655	16	86.139	30
23	Gen. Gamma (4P)	0.20463	25	7.2031	20	86.139	29
20	Gamma (3P)	0.20617	26	7.18	19	78.868	24
43	Nakagami	0.20734	27	9.506	35	129.92	42
33	Laplace	0.21055	28	4.6316	6	48.625	10
11	Error	0.21055	29	4.6316	7	48.625	9
47	Pearson 5	0.21409	30	8.8947	31	69.248	21
63	Weibull (3P)	0.21658	31	9.1869	33	96.252	36
28	Hypersecant	0.22509	32	6.0943	9	55.094	13
40	Logistic	0.22909	33	6.9376	13	60.943	18
30	Inv. Gaussian (3P)	0.23246	34	7.5451	25	70.082	22
44	Normal	0.2338	35	8.3938	30	81.651	26
18	Frechet (3P)	0.23537	36	16.421	42	N/A	
1	Beta	0.23809	37	11.345	36	84.111	27
62	Weibull	0.23855	38	9.2174	34	81.46	25
60	Uniform	0.25097	39	41.601	55	N/A	
39	Log-Pearson 3	0.25767	40	38.773	53	N/A	
51	Pert	0.26696	41	13.692	39	117.81	40
17	Frechet	0.26991	42	12.881	37	114.18	39
59	Triangular	0.27395	43	14.494	40	142.44	43
55	Rayleigh (2P)	0.27922	44	13.24	38	108.54	37
54	Rayleigh	0.28269	45	15.818	41	208.05	46
27	Gumbel Min	0.30226	46	19.15	43	60.511	17
5	Chi-Squared	0.38863	47	410.03	61	120.41	41
32	Kumaraswamy	0.39053	48	20.875	44	165.18	44
14	Exponential (2P)	0.41577	49	28.116	46	249.13	47
53	Power Function	0.43762	50	26.597	45	263.44	48
13	Exponential	0.44622	51	30.504	47	438.26	51
56	Reciprocal	0.45907	52	30.52	48	299.69	49
45	Pareto	0.48144	53	37.326	52	507.18	53
46	Pareto 2	0.4907	54	35.852	51	441.48	52
35	Levy (2P)	0.49497	55	34.781	50	555.53	54
6	Chi-Squared (2P)	0.50867	56	339.84	60	75.383	23
34	Levy	0.54022	57	41.598	54	682.03	56
3	Burr (4P)	0.61161	58	54.075	56	N/A	
7	Dagum	0.63685	59	66.257	57	575.95	55
52	Phased Bi-Exponential	0.63736	60	100.97	59	320.64	50
8	Dagum (4P)	0.65408	61	77.278	58	176.5	45

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	**Rank**	**Statistic**	**Rank**	**Statistic**	**Rank**
12	Error Function	0.93181	62	650.34	62	N/A	
58	Student's t	1.0	63	1790.5	63	1.8915E+9	57
64	Johnson SB	No fit					
65	Phased Bi-Weibull	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Wakeby [#61]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	108 0.09796 0.23536 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.10325	0.11768	0.13067	0.14607	0.15675
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	108 1.0619 2				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	6 24.411 4.3880E-4 3				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	8.5581	10.645	12.592	15.033	16.812
Reject?	Yes	Yes	Yes	Yes	Yes

Normal [#44]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	108 0.2338 1.1426E-5 35				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.10325	0.11768	0.13067	0.14607	0.15675
Reject?	Yes	Yes	Yes	Yes	Yes
Anderson-Darling					
Sample Size Statistic Rank	108 8.3938 30				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	5 81.651 3.3307E-16 26				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	7.2893	9.2364	11.07	13.388	15.086
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters for the Best-Fit and Normal Distributions:

#	Distribution	Parameters
44	Normal	s=1592.6 m=5538.3
61	Wakeby	a=51152.0 b=13.15 g=411.72 d=0.46168 x=1158.6

Summary:

The observed tank sizes were not normally distributed (n = 108; Kolmogorov-Smirnov statistic and P-value = 0.2338, 0.0, respectively; Chi-Squared statistic, DF and P-value = 81.651, 5, 0.0, respectively).

Moreton Bay Roof Areas

Descriptive Statistics (note roof sizes are in m^2):

Statistic	Value
Sample Size	108
Range	225
Mean	102.07
Variance	2190.3
Std. Deviation	46.801
Coef. of Variation	0.4585
Std. Error	4.5034
Skewness	0.31812
Excess Kurtosis	0.07963

Percentile	Value
Min	14
5%	25.9
10%	35.9
25% (Q1)	68.75
50% (Median)	104
75% (Q3)	133.75
90%	158.2
95%	192.55
Max	239

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
62	Wakeby	0.04317	1	0.15625	1	3.2922	3
7	Dagum	0.04857	2	0.32164	2	3.0334	1
6	Chi-Squared (2P)	0.05865	3	0.47213	4	5.7577	10
11	Error	0.06262	4	0.46865	3	6.6821	13
31	Johnson SB	0.06272	5	0.55907	9	6.5044	12
42	Lognormal (3P)	0.06431	6	0.59789	11	7.2873	19
44	Normal	0.0648	7	0.47873	5	6.7089	14
16	Fatigue Life (3P)	0.06517	8	0.6067	12	7.3179	20
50	Pearson 6 (4P)	0.06545	9	0.60985	13	7.3359	21
48	Pearson 5 (3P)	0.0664	10	0.62895	15	7.6417	23
20	Gamma (3P)	0.06715	11	0.62832	14	8.1921	24
51	Pert	0.0677	12	3.1645	40	10.062	31
24	Gen. Logistic	0.0683	13	0.53184	6	6.443	11
21	Gen. Extreme Value	0.06836	14	0.53821	7	5.1968	7
38	Log-Logistic (3P)	0.06878	15	0.56184	10	6.7094	15
43	Nakagami	0.06901	16	0.92792	25	9.1707	28
2	Burr	0.06968	17	0.67595	17	3.7202	5
64	Weibull (3P)	0.07323	18	0.69721	18	3.7159	4
40	Logistic	0.07378	19	0.55257	8	7.2433	18
23	Gen. Gamma (4P)	0.0744	20	0.66014	16	5.6569	8
3	Burr (4P)	0.0762	21	0.70589	19	9.1273	27
30	Inv. Gaussian (3P)	0.0773	22	0.74975	20	9.5276	29
10	Erlang (3P)	0.07776	23	0.78839	22	9.6861	30
63	Weibull	0.08388	24	0.85073	24	6.7401	16
39	Log-Pearson 3	0.08409	25	0.81136	23	5.0565	6
28	Hypersecant	0.08419	26	0.76439	21	8.8105	26
27	Gumbel Min	0.08923	27	2.7916	36	3.114	2
1	Beta	0.09142	28	2.8923	37	6.8519	17
33	Laplace	0.09415	29	1.3306	29	12.248	33
4	Cauchy	0.09428	30	1.6219	30	10.374	32
58	Rice	0.09464	31	0.96597	26	5.6654	9
56	Rayleigh (2P)	0.09578	32	1.0385	27	7.6129	22
55	Rayleigh	0.09587	33	1.2107	28	8.3669	25
19	Gamma	0.10083	34	1.8631	33	16.653	37
26	Gumbel Max	0.10788	35	2.3679	35	21.93	38
25	Gen. Pareto	0.10954	36	23.535	56	N/A	
22	Gen. Gamma	0.11396	37	1.6907	31	14.753	35
49	Pearson 6	0.11497	38	1.805	32	12.77	34
60	Triangular	0.11553	39	1.9625	34	15.402	36
61	Uniform	0.12102	40	23.687	57	N/A	
29	Inv. Gaussian	0.12575	41	5.0671	43	28.553	43
41	Lognormal	0.14112	42	2.9946	38	26.133	41

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
37	Log-Logistic	0.14971	43	3.0819	39	25.868	40
36	Log-Gamma	0.15759	44	3.9499	42	27.099	42
15	Fatigue Life	0.16383	45	3.6617	41	23.392	39
53	Phased Bi-Weibull	0.16569	46	8.2082	48	54.464	50
47	Pearson 5	0.18617	47	5.2549	44	41.453	46
54	Power Function	0.1927	48	7.1531	46	52.87	49
17	Frechet	0.21565	49	7.6179	47	43.419	47
14	Exponential (2P)	0.22935	50	10.011	49	62.531	51
32	Kumaraswamy	0.23497	51	6.3646	45	34.593	45
52	Phased Bi-Exponential	0.237	52	17.928	53	50.329	48
9	Erlang	0.24447	53	10.147	50	29.087	44
18	Frechet (3P)	0.25052	54	14.389	52	N/A	
13	Exponential	0.25121	55	13.918	51	79.435	53
5	Chi-Squared	0.27145	56	117.08	62	105.86	56
57	Reciprocal	0.32222	57	19.63	55	79.833	54
45	Pareto	0.35498	58	26.445	59	76.904	52
46	Pareto 2	0.37297	59	29.814	60	104.6	55
35	Levy (2P)	0.38251	60	18.599	54	167.96	58
34	Levy	0.43285	61	24.327	58	169.12	59
8	Dagum (4P)	0.44573	62	49.641	61	119.65	57
12	Error Function	0.71387	63	240.63	63	948.28	60
59	Student's t	0.99747	64	871.39	64	2.3681E+5	61
65	Johnson SU	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Wakeby [#62]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	108 0.04317 0.9827 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.10325	0.11768	0.13067	0.14607	0.15675
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	108 0.15625 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	6 3.2922 0.77138 3				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	8.5581	10.645	12.592	15.033	16.812
Reject?	No	No	No	No	No

Normal [#44]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	108 0.0648 0.73001 7				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.10325	0.11768	0.13067	0.14607	0.15675
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	108 0.47873 5				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	6 6.7089 0.34861 14				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	8.5581	10.645	12.592	15.033	16.812
Reject?	No	No	No	No	No

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
44	Normal	s=46.801 m=102.07
62	Wakeby	a=247.63 b=2.6277 g=16.657 d=0.20336 x=12.903

Summary:

The observed roof areas were normally distributed (n = 108; Kolmogorov-Smirnov statistic and P-value = 0.0648, 0.73, respectively; Chi-Squared statistic, DF and P-value = 6.7089, 6, 0.35, respectively).

Sunshine Coast Tank Sizes

Descriptive Statistics (note tank sizes are in litres):

Statistic	Value
Sample Size	438
Range	26648.0
Mean	5629.3
Variance	2.1125E+7
Std. Deviation	4596.1
Coef. of Variation	0.81646
Std. Error	219.61
Skewness	2.6952
Excess Kurtosis	7.5994

Percentile	Value
Min	2664.8
5%	2664.8
10%	2664.8
25% (Q1)	2664.8
50% (Median)	4441.3
75% (Q3)	5329.5
90%	9326.7
95%	19120.0
Max	29312.0

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
16	Frechet	0.16055	1	16.099	2	442.19	20
23	Gen. Logistic	0.16374	2	18.062	5	407.33	8
38	Log-Pearson 3	0.16652	3	16.084	1	408.05	9
20	Gen. Extreme Value	0.16898	4	18.354	6	414.75	11
24	Gen. Pareto	0.18084	5	17.99	3	379.89	3
59	Wakeby	0.18084	6	17.99	4	379.89	4
47	Pearson 6	0.1999	7	19.592	7	397.19	6
45	Pearson 5	0.20053	8	19.707	8	397.34	7
35	Log-Gamma	0.22335	9	22.021	10	418.68	14
4	Cauchy	0.22656	10	24.813	12	475.9	26
36	Log-Logistic	0.22968	11	21.973	9	417.99	13
40	Lognormal	0.23219	12	23.623	11	422.71	15
41	Lognormal (3P)	0.24712	13	423.6	50	N/A	
30	Johnson SB	0.25325	14	451.47	52	N/A	
37	Log-Logistic (3P)	0.25672	15	403.58	49	N/A	
14	Fatigue Life	0.25685	16	27.529	13	452.96	22
28	Inv. Gaussian	0.26184	17	27.608	14	497.2	29
25	Gumbel Max	0.2769	18	39.221	17	509.7	32

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
61	Weibull (3P)	0.27854	19	558.58	54	481.59	27
19	Gamma (3P)	0.27854	20	99.715	34	494.39	28
22	Gen. Gamma (4P)	0.27854	21	104.91	36	515.34	33
21	Gen. Gamma	0.27955	22	35.7	15	431.92	17
43	Pareto	0.27961	23	102.33	35	527.06	34
13	Exponential (2P)	0.28022	24	129.1	40	541.47	35
60	Weibull	0.29447	25	41.037	18	417.66	12
18	Gamma	0.29916	26	37.317	16	444.49	21
42	Normal	0.30912	27	54.909	25	469.61	25
2	Burr	0.31133	28	188.92	43	N/A	
58	Uniform	0.3138	29	150.98	42	N/A	
52	Rayleigh	0.31737	30	48.397	19	414.26	10
39	Logistic	0.32139	31	51.457	21	440.76	19
3	Burr (4P)	0.32275	32	458.68	53	1121.2	49
27	Hypersecant	0.33148	33	51.132	20	432.62	18
29	Inv. Gaussian (3P)	0.35697	34	54.776	24	509.66	31
53	Rayleigh (2P)	0.35756	35	60.066	28	388.18	5
10	Error	0.35837	36	55.454	26	462.4	24
32	Laplace	0.35837	37	55.454	27	462.4	23
44	Pareto 2	0.37274	38	53.32	22	610.27	38
34	Levy (2P)	0.37488	39	65.078	29	653.71	40
26	Gumbel Min	0.37618	40	120.04	39	497.81	30
12	Exponential	0.3771	41	53.854	23	550.24	36
1	Beta	0.38669	42	89.99	31	676.71	42
55	Rice	0.39299	43	76.328	30	431.8	16
7	Dagum	0.39304	44	93.553	32	682.9	43
51	Power Function	0.39898	45	97.408	33	992.96	48
33	Levy	0.39918	46	119.19	38	910.46	47
49	Pert	0.43106	47	266.03	45	573.29	37
8	Dagum (4P)	0.43518	48	428.49	51	791.28	46
15	Fatigue Life (3P)	0.45565	49	138.92	41	665.45	41
54	Reciprocal	0.49332	50	860.28	56	632.75	39
17	Frechet (3P)	0.49676	51	329.95	48	1738.4	52
9	Erlang	0.50841	52	114.5	37	753.04	45
46	Pearson 5 (3P)	0.56313	53	224.11	44	69.527	2
57	Triangular	0.57955	54	566.95	55	748.48	44
48	Pearson 6 (4P)	0.59995	55	289.54	46	56.96	1
6	Chi-Squared (2P)	0.63328	56	10360.0	59	1533.9	50
31	Kumaraswamy	0.67774	57	1295.9	57	1910.2	54
11	Error Function	0.71897	58	325.77	47	1625.9	51
5	Chi-Squared	0.75592	59	39771.0	60	1855.7	53
56	Student's t	1.0	60	7003.3	58	5.6430E+9	55
50	Phased Bi-Exponential	1.4764	61	N/A		N/A	

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
62	Erlang (3P)	No fit					
63	Johnson SU	No fit					
64	Nakagami	No fit					
65	Phased Bi-Weibull	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Frechet [#16]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	438 0.16055 2.5165E-10 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.05127	0.05844	0.06489	0.07253	0.07784
Reject?	Yes	Yes	Yes	Yes	Yes
Anderson-Darling					
Sample Size Statistic Rank	438 16.099 2				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	8 442.19 0 20				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	11.03	13.362	15.507	18.168	20.09
Reject?	Yes	Yes	Yes	Yes	Yes

Normal [#42]					
Kolmogorov-Smirnov					
Sample Size	438				
Statistic	0.30912				
P-Value	0				
Rank	27				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.05127	0.05844	0.06489	0.07253	0.07784
Reject?	Yes	Yes	Yes	Yes	Yes
Anderson-Darling					
Sample Size	438				
Statistic	54.909				
Rank	25				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom	8				
Statistic	469.61				
P-Value	0				
Rank	25				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	11.03	13.362	15.507	18.168	20.09
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best-Fit and Normal Distributions:

#	**Distribution**	**Parameters**
16	Frechet	a=2.1862 b=3547.7
42	Normal	s=4596.1 m=5629.3

Summary:

The observed tank sizes were not normally distributed (n = 438; Kolmogorov-Smirnov statistic and P-value = 0.30912, 0, respectively; Chi-Squared statistic, DF and P-value = 469.61, 8, 0, respectively).

Sunshine Coast Roof Areas

Observed data was not available. The study assumed Moreton Bay roof areas for Sunshine Coast.

Gold Coast Tank Sizes

Descriptive Statistics (note tank sizes are in litres):

Statistic	Value
Sample Size	31
Range	3750
Mean	5613.9
Variance	7.3845E+5
Std. Deviation	859.33
Coef. of Variation	0.15307
Std. Error	154.34
Skewness	0.92113
Excess Kurtosis	1.6976

Percentile	Value
Min	4115
5%	4162.4
10%	4524.0
25% (Q1)	5252
50% (Median)	5577
75% (Q3)	5926
90%	6943.0
95%	7837.4
Max	7865

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
62	Wakeby	0.07894	1	0.21425	1	1.0007	5
4	Cauchy	0.08015	2	0.27962	2	0.73912	3
2	Burr	0.11008	3	0.45162	3	2.0475	38
38	Log-Logistic (3P)	0.11449	4	0.46396	5	2.0325	37
24	Gen. Logistic	0.12412	5	0.48007	6	2.0883	39
33	Laplace	0.1281	6	0.45477	4	1.5687	30
49	Pearson 6	0.1319	7	0.64928	13	1.9733	35
47	Pearson 5	0.13198	8	0.6485	12	3.2985	40
11	Error	0.13374	9	0.54473	7	1.5484	29
41	Lognormal	0.13427	10	0.67883	19	1.9696	34
15	Fatigue Life	0.13522	11	0.68531	24	1.9641	33
36	Log-Gamma	0.13586	12	0.68212	21	1.9923	36
10	Erlang (3P)	0.13605	13	0.68394	23	1.2215	10
51	Pert	0.13734	14	3.7077	43	1.0968	6
48	Pearson 5 (3P)	0.13752	15	0.64763	10	1.2388	16
50	Pearson 6 (4P)	0.13753	16	0.64772	11	1.2388	15
16	Fatigue Life (3P)	0.13754	17	0.6681	17	1.2275	12
42	Lognormal (3P)	0.13768	18	0.65728	14	1.2334	14
23	Gen. Gamma (4P)	0.1378	19	0.67909	20	1.2223	11
20	Gamma (3P)	0.1381	20	0.68332	22	1.2207	9
28	Hypersecant	0.13848	21	0.58303	8	1.5278	27
63	Weibull	0.14085	22	1.578	38	1.6072	31
21	Gen. Extreme Value	0.1419	23	0.66654	16	1.2321	13
40	Logistic	0.14286	24	0.7002	25	1.4947	26
22	Gen. Gamma	0.14292	25	0.74148	27	1.3209	19
39	Log-Pearson 3	0.14587	26	0.67322	18	1.274	17
31	Johnson SU	0.14748	27	0.66283	15	1.2833	18
19	Gamma	0.14836	28	0.77438	29	1.389	23

#	**Distribution**	**Kolmogorov Smirnov**		**Anderson Darling**		**Chi-Squared**	
		Statistic	**Rank**	**Statistic**	**Rank**	**Statistic**	**Rank**
37	Log-Logistic	0.15003	29	0.59757	9	1.4565	25
64	Weibull (3P)	0.15158	30	0.82613	30	1.1844	7
26	Gumbel Max	0.15571	31	0.74241	28	0.71518	2
18	Frechet (3P)	0.15678	32	0.7372	26	0.80821	4
43	Nakagami	0.16015	33	0.91964	35	1.5444	28
56	Rayleigh (2P)	0.1608	34	0.85549	33	1.2004	8
44	Normal	0.1628	35	0.94982	36	1.4467	24
30	Inv. Gaussian (3P)	0.16615	36	0.8538	32	1.3431	20
9	Erlang	0.16639	37	0.857	34	1.3673	21
29	Inv. Gaussian	0.16827	38	0.84453	31	1.3696	22
25	Gen. Pareto	0.17477	39	8.5682	51	N/A	
1	Beta	0.18667	40	3.3506	42	1.7419	32
53	Phased Bi-Weibull	0.19862	41	3.2605	41	N/A	
60	Triangular	0.20373	42	3.7482	44	3.3548	41
61	Uniform	0.20699	43	12.392	57	N/A	
17	Frechet	0.20895	44	1.2055	37	7.9368	43
27	Gumbel Min	0.21504	45	3.1119	39	4.4388	42
57	Reciprocal	0.255	46	3.1523	40	20.371	47
32	Kumaraswamy	0.30253	47	3.9845	45	10.371	45
14	Exponential (2P)	0.3068	48	5.1044	47	10.336	44
54	Power Function	0.31317	49	4.8908	46	0.66667	1
45	Pareto	0.33484	50	5.9739	49	30.071	48
55	Rayleigh	0.34426	51	6.452	50	43.242	50
35	Levy (2P)	0.3762	52	5.7776	48	68.63	51
5	Chi-Squared	0.40381	53	84.459	59	13.274	46
6	Chi-Squared (2P)	0.4889	54	240.78	61	38.395	49
7	Dagum	0.49407	55	10.197	52	191.45	54
46	Pareto 2	0.51018	56	10.375	53	153.85	53
8	Dagum (4P)	0.51452	57	11.029	55	N/A	
13	Exponential	0.51954	58	10.66	54	153.0	52
3	Burr (4P)	0.52011	59	11.271	56	N/A	
34	Levy	0.5968	60	13.813	58	246.37	55
58	Rice	0.82698	61	305.42	62	N/A	
52	Phased Bi-Exponential	0.99183	62	189.4	60	12292.0	56
12	Error Function	1.0	63	720.21	64	N/A	
59	Student's t	1.0	64	520.2	63	1.0409E+9	57
65	Johnson SB	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Wakeby [#62]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	31 0.07894 0.98206 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.18732	0.21412	0.23788	0.26596	0.2853
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	31 0.21425 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	4 1.0007 0.90968 5				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	5.9886	7.7794	9.4877	11.668	13.277
Reject?	No	No	No	No	No

Normal [#44]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	31 0.1628 0.34585 35				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.18732	0.21412	0.23788	0.26596	0.2853
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	31 0.94982 36				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	3 1.4467 0.69462 24				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	4.6416	6.2514	7.8147	9.8374	11.345
Reject?	No	No	No	No	No

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
44	Normal	s=859.33 m=5613.9
62	Wakeby	a=12580.0 b=8.1431 g=434.96 d=0.23826 x=3667.0

Summary:

The observed tank sizes were normally distributed (n = 31; Kolmogorov-Smirnov statistic and P-value = 0.1628, 0.35, respectively; Chi-Squared statistic, DF and P-value = 1.4467, 3, 0.69, respectively).

Gold Coast Roof Areas

Descriptive Statistics (note roof sizes are in m^2):

Statistic	Value
Sample Size	31
Range	168
Mean	97.613
Variance	1954.8
Std. Deviation	44.213
Coef. of Variation	0.45294
Std. Error	7.9409
Skewness	0.67161
Excess Kurtosis	-0.08977

Percentile	Value
Min	29
5%	32.0
10%	48.4
25% (Q1)	62
50% (Median)	94
75% (Q3)	122
90%	175.8
95%	191.0
Max	197

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
18	Frechet (3P)	0.06871	1	0.20194	12	1.6665	35
42	Lognormal (3P)	0.06883	2	0.19799	10	1.6463	30
30	Inv. Gaussian (3P)	0.06959	3	0.19623	7	1.6341	27
48	Pearson 5 (3P)	0.0698	4	0.20147	11	1.6507	32
16	Fatigue Life (3P)	0.06985	5	0.19572	6	1.6349	28
50	Pearson 6 (4P)	0.07012	6	0.19768	9	1.6397	29
26	Gumbel Max	0.07129	7	0.22506	18	1.9184	40
38	Log-Logistic (3P)	0.07159	8	0.21948	17	1.9841	41
20	Gamma (3P)	0.07276	9	0.19463	5	1.6244	26
22	Gen. Gamma	0.07416	10	0.19678	8	1.5829	23
29	Inv. Gaussian	0.07501	11	0.34485	28	0.99346	10
19	Gamma	0.07511	12	0.19148	4	1.6025	25
2	Burr	0.07526	13	0.21642	16	1.697	37
21	Gen. Extreme Value	0.07616	14	0.18796	2	1.7366	38
7	Dagum	0.07738	15	0.21161	15	0.9204	8
39	Log-Pearson 3	0.07775	16	0.1827	1	1.666	34
24	Gen. Logistic	0.07817	17	0.23186	19	0.67099	6
64	Weibull (3P)	0.08083	18	0.20515	13	1.5183	22

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
62	Wakeby	0.08381	19	0.18984	3	1.6748	36
41	Lognormal	0.08615	20	0.23661	21	1.1118	15
56	Rayleigh (2P)	0.08743	21	0.26208	24	1.0964	14
49	Pearson 6	0.08899	22	0.23261	20	1.0961	13
58	Rice	0.0907	23	0.38776	29	1.3664	20
43	Nakagami	0.0918	24	0.25469	23	1.3523	19
15	Fatigue Life	0.09263	25	0.25055	22	1.0903	12
63	Weibull	0.09277	26	0.34299	27	1.2124	17
31	Johnson SB	0.09356	27	0.21105	14	1.5087	21
36	Log-Gamma	0.10092	28	0.30443	25	1.0666	11
6	Chi-Squared (2P)	0.10337	29	0.4843	32	0.63546	5
44	Normal	0.10652	30	0.52368	33	0.57784	3
60	Triangular	0.10764	31	1.5733	42	1.6619	33
37	Log-Logistic	0.10862	32	0.33372	26	0.47167	2
1	Beta	0.10879	33	1.2385	41	1.1749	16
25	Gen. Pareto	0.10915	34	7.6409	55	N/A	
11	Error	0.10966	35	0.53156	34	0.60005	4
55	Rayleigh	0.11455	36	0.46264	31	2.3569	42
40	Logistic	0.11997	37	0.53344	35	1.2941	18
47	Pearson 5	0.12029	38	0.43003	30	0.33403	1
23	Gen. Gamma (4P)	0.1224	39	4.3961	51	N/A	
51	Pert	0.12376	40	3.4994	50	0.98061	9
4	Cauchy	0.13112	41	0.71743	37	2.6208	44
28	Hypersecant	0.13215	42	0.59964	36	3.2863	45
10	Erlang (3P)	0.13823	43	0.80021	38	1.6491	31
61	Uniform	0.15989	44	14.525	61	N/A	
33	Laplace	0.16038	45	0.80496	39	3.3077	46
54	Power Function	0.16128	46	1.6519	43	1.5981	24
27	Gumbel Min	0.16891	47	2.3367	46	2.5261	43
17	Frechet	0.16899	48	0.95675	40	0.67518	7
14	Exponential (2P)	0.18826	49	2.6388	48	4.4844	47
3	Burr (4P)	0.19115	50	1.6777	44	4.7741	48
32	Kumaraswamy	0.20048	51	1.7258	45	1.7419	39
57	Reciprocal	0.20305	52	2.5228	47	5.6129	50
9	Erlang	0.22997	53	2.9479	49	5.4215	49
45	Pareto	0.30234	54	6.4125	54	13.565	53
52	Phased Bi-Exponential	0.30994	55	9.1136	58	15.454	54
13	Exponential	0.32392	56	4.4595	52	15.713	55
5	Chi-Squared	0.33722	57	28.434	62	26.151	58
35	Levy (2P)	0.36347	58	4.5016	53	13.462	52
8	Dagum (4P)	0.39978	59	11.29	59	21.188	57
46	Pareto 2	0.41896	60	8.2126	56	19.698	56
34	Levy	0.47164	61	8.2492	57	42.107	59

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
53	Phased Bi-Weibull	0.6034	62	14.164	60	12.104	51
12	Error Function	0.79667	63	69.663	63	238.11	60
59	Student's t	0.99941	64	251.59	64	1.3225E+5	61
65	Johnson SU	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Frechet (3P) [#18]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	31 0.06871 0.99635 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.18732	0.21412	0.23788	0.26596	0.2853
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	31 0.20194 12				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	4 1.6665 0.7968 35				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	5.9886	7.7794	9.4877	11.668	13.277
Reject?	No	No	No	No	No

Normal [#44]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	31 0.10652 0.83693 30				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.18732	0.21412	0.23788	0.26596	0.2853
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	31 0.52368 33				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	4 0.57784 0.96549 3				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	5.9886	7.7794	9.4877	11.668	13.277
Reject?	No	No	No	No	No

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
18	Frechet (3P)	a=3.7392E+7 b=1.3154E+9 g=-1.3154E+9
44	Normal	s=44.213 m=97.613

Summary:

The observed roof areas were normally distributed (n = 31; Kolmogorov-Smirnov statistic and P-value = 0.10652, 0.84, respectively; Chi-Squared statistic, DF and P-value = 0.57784, 3, 0.97, respectively).

Ipswich Tank Sizes

Descriptive Statistics (note tank sizes are in litres):

Statistic	Value
Sample Size	258
Range	21318.0
Mean	6667.0
Variance	1.7545E+7
Std. Deviation	4188.7
Coef. of Variation	0.62828
Std. Error	260.78
Skewness	2.1125
Excess Kurtosis	4.4628

Percentile	Value
Min	2664.8
5%	2664.8
10%	3872.8
25% (Q1)	4441.3
50% (Median)	4441.3
75% (Q3)	7994.3
90%	10215.0
95%	19564.0
Max	23983.0

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
30	Inv. Gaussian (3P)	0.22082	1	12.58	4	95.811	4
42	Lognormal (3P)	0.22088	2	12.571	3	96.178	5
38	Log-Logistic (3P)	0.22225	3	12.854	8	157.88	7
16	Fatigue Life (3P)	0.22323	4	12.725	7	95.563	3
47	Pearson 5 (3P)	0.22469	5	12.618	5	165.32	8
39	Log-Pearson 3	0.22511	6	12.48	2	97.451	6
18	Frechet (3P)	0.2261	7	12.689	6	346.2	15
17	Frechet	0.22628	8	12.281	1	166.36	9
51	Phased Bi-Exponential	0.23021	9	19.524	22	410.5	26
59	Uniform	0.23033	10	94.962	51	N/A	
2	Burr	0.23152	11	13.216	9	332.73	14
19	Gamma	0.23257	12	17.215	19	491.14	42
29	Inv. Gaussian	0.23304	13	14.144	13	466.3	38
26	Gumbel Max	0.23309	14	17.56	20	365.77	16
60	Wakeby	0.23383	15	100.0	53	N/A	
25	Gen. Pareto	0.23383	16	100.0	52	N/A	
21	Gen. Extreme Value	0.24061	17	14.264	14	426.49	28
10	Erlang (3P)	0.24218	18	44.768	38	389.02	22
14	Exponential (2P)	0.24218	19	42.173	37	389.02	21
24	Gen. Logistic	0.24981	20	14.5	16	428.24	30
48	Pearson 6	0.25075	21	13.379	11	376.09	19
46	Pearson 5	0.25097	22	13.376	10	375.92	18
36	Log-Gamma	0.25763	23	14.135	12	387.89	20
41	Lognormal	0.26307	24	14.741	17	398.16	25
37	Log-Logistic	0.26456	25	14.478	15	427.12	29
43	Normal	0.26793	26	25.501	28	537.81	46
53	Rayleigh	0.26851	27	20.151	23	449.45	36
22	Gen. Gamma	0.26875	28	17.733	21	328.43	13
15	Fatigue Life	0.26986	29	15.392	18	413.04	27
35	Levy (2P)	0.27342	30	32.646	32	606.29	48
62	Weibull (3P)	0.28174	31	49.902	40	366.25	17
31	Johnson SB	0.28633	32	102.26	54	N/A	
40	Logistic	0.28898	33	24.023	26	474.79	40
61	Weibull	0.28947	34	22.351	24	441.17	33
56	Rice	0.29063	35	22.909	25	444.13	34
28	Hypersecant	0.30433	36	24.239	27	466.85	39
27	Gumbel Min	0.31993	37	60.327	47	518.04	45
50	Pert	0.32012	38	52.102	41	390.19	23
54	Rayleigh (2P)	0.32584	39	27.361	31	429.57	31
11	Error	0.32989	40	26.351	29	506.56	44
33	Laplace	0.32989	41	26.351	30	506.56	43
55	Reciprocal	0.33189	42	72.884	48	485.09	41

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
7	Dagum	0.33512	43	33.866	33	236.13	11
4	Cauchy	0.35736	44	56.142	43	323.76	12
23	Gen. Gamma (4P)	0.35975	45	53.487	42	445.78	35
44	Pareto	0.36538	46	56.366	44	453.01	37
45	Pareto 2	0.36776	47	37.827	35	814.26	52
13	Exponential	0.37005	48	38.016	36	813.06	51
20	Gamma (3P)	0.37408	49	56.664	45	394.5	24
9	Erlang	0.38662	50	37.456	34	194.41	10
3	Burr (4P)	0.40463	51	129.32	57	N/A	
58	Triangular	0.42687	52	122.45	56	439.87	32
34	Levy	0.44048	53	74.78	49	1074.1	53
52	Power Function	0.44382	54	48.8	39	550.77	47
1	Beta	0.47008	55	57.895	46	N/A	
8	Dagum (4P)	0.55656	56	87.95	50	7.4386	1
49	Pearson 6 (4P)	0.59405	57	122.01	55	25.337	2
32	Kumaraswamy	0.60019	58	228.66	58	770.34	50
5	Chi-Squared	0.62399	59	21934.0	62	697.67	49
12	Error Function	0.73922	60	310.96	59	2793.0	55
6	Chi-Squared (2P)	0.76357	61	9446.4	61	1112.0	54
57	Student's t	1.0	62	4257.9	60	7.4809E+9	56
63	Johnson SU	No fit					
64	Nakagami	No fit					
65	Phased Bi-Weibull	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Inv. Gaussian (3P) [#30]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	258 0.22082 1.7001E-11 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.0668	0.07614	0.08455	0.09451	0.10142
Reject?	Yes	Yes	Yes	Yes	Yes
Anderson-Darling					
Sample Size Statistic Rank	258 12.58 4				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes

Chi-Squared					
Deg. of freedom Statistic P-Value Rank	7 95.811 0 4				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	9.8032	12.017	14.067	16.622	18.475
Reject?	Yes	Yes	Yes	Yes	Yes

Normal [#43]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	258 0.26793 1.0094E-16 26				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.0668	0.07614	0.08455	0.09451	0.10142
Reject?	Yes	Yes	Yes	Yes	Yes
Anderson-Darling					
Sample Size Statistic Rank	258 25.501 28				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	7 537.81 0 46				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	9.8032	12.017	14.067	16.622	18.475
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
30	Inv. Gaussian (3P)	l=7147.9 m=4897.5 g=1769.4
43	Normal	s=4188.7 m=6667.0

Summary:

The observed tank sizes were not normally distributed (n = 258; Kolmogorov-Smirnov statistic and P-value = 0.2679, 0, respectively; Chi-Squared statistic, DF and P-value = 537.81, 7, 0, respectively).

Ipswich Roof Areas

Observed data was not available. The study assumed Moreton Bay roof areas for Ipswich.

APPENDIX B: Fitting Probability Distributions to Modelled Tank Yield

Brisbane

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	112.19
Mean	43.369
Variance	217.18
Std. Deviation	14.737
Coef. of Variation	0.3398
Std. Error	0.14737
Skewness	0.47898
Excess Kurtosis	0.45299

Percentile	Value
Min	4.6393
5%	21.298
10%	25.314
25% (Q1)	33.017
50% (Median)	42.264
75% (Q3)	52.456
90%	62.731
95%	69.698
Max	116.83

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
31	Johnson SU	0.00606	1	0.44284	1	23.189	1
42	Lognormal (3P)	0.00734	2	0.55738	2	26.446	6
16	Fatigue Life (3P)	0.0079	3	0.64357	3	24.75	3
2	Burr	0.00875	4	1.1458	8	24.301	2
21	Gen. Extreme Value	0.00876	5	1.011	5	29.346	9
20	Gamma (3P)	0.00896	6	0.83096	4	25.249	4
3	Burr (4P)	0.00901	7	1.2884	10	26.089	5
23	Gen. Gamma (4P)	0.00928	8	1.2279	9	29.21	8
10	Erlang (3P)	0.00944	9	1.0724	6	26.971	7
1	Beta	0.01109	10	1.1121	7	29.369	10
62	Wakeby	0.01487	11	403.51	44	N/A	
7	Dagum	0.01576	12	4.7581	11	56.527	12
38	Log-Logistic (3P)	0.01732	13	6.1009	12	58.314	13
43	Nakagami	0.01908	14	6.5304	13	68.532	16
19	Gamma	0.02014	15	7.4966	14	65.978	14
6	Chi-Squared (2P)	0.02039	16	15.397	18	80.969	19
24	Gen. Logistic	0.02133	17	8.2881	15	69.875	17
50	Pearson 6 (4P)	0.02484	18	9.565	16	50.171	11
22	Gen. Gamma	0.02617	19	10.479	17	77.515	18
64	Weibull (3P)	0.02897	20	18.953	19	154.99	20
32	Kumaraswamy	0.02934	21	19.798	20	161.78	21
63	Weibull	0.03149	22	25.554	22	166.78	22
39	Log-Pearson 3	0.03253	23	171.38	38	N/A	
44	Normal	0.0347	24	25.006	21	179.22	25
11	Error	0.03631	25	26.339	23	179.15	24

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
30	Inv. Gaussian (3P)	0.03667	26	28.388	24	67.239	15
29	Inv. Gaussian	0.03715	27	50.285	27	281.26	28
40	Logistic	0.03894	28	32.963	25	216.11	26
26	Gumbel Max	0.03979	29	56.337	32	345.85	31
37	Log-Logistic	0.0464	30	42.198	26	281.62	29
58	Rice	0.04698	31	53.714	30	259.26	27
41	Lognormal	0.0506	32	51.344	28	312.99	30
25	Gen. Pareto	0.05272	33	1809.5	52	N/A	
28	Hypersecant	0.05441	34	54.95	31	381.87	32
49	Pearson 6	0.05568	35	51.71	29	170.37	23
15	Fatigue Life	0.06148	36	74.107	33	388.33	33
36	Log-Gamma	0.06383	37	82.178	34	488.99	34
61	Uniform	0.074	38	2127.7	56	N/A	
33	Laplace	0.08079	39	114.97	35	805.92	36
47	Pearson 5	0.08255	40	152.01	37	991.95	38
4	Cauchy	0.08771	41	140.91	36	1688.7	41
27	Gumbel Min	0.10411	42	404.92	45	1513.3	39
51	Pert	0.10477	43	336.74	40	2020.6	43
9	Erlang	0.11358	44	301.09	39	616.96	35
5	Chi-Squared	0.11548	45	798.17	48	3712.9	47
17	Frechet	0.12236	46	352.48	42	1792.4	42
53	Phased Bi-Weibull	0.12875	47	350.42	41	807.86	37
56	Rayleigh (2P)	0.13537	48	362.65	43	1566.1	40
55	Rayleigh	0.13614	49	476.85	46	2754.7	44
48	Pearson 5 (3P)	0.13931	50	531.55	47	3072.2	45
18	Frechet (3P)	0.21013	51	857.15	50	N/A	
60	Triangular	0.21444	52	832.76	49	3297.4	46
52	Phased Bi-Exponential	0.2358	53	2022.2	54	12566.0	50
14	Exponential (2P)	0.31473	54	1770.9	51	10309.0	48
54	Power Function	0.33641	55	1878.3	53	11801.0	49
13	Exponential	0.34616	56	2029.7	55	12760.0	51
57	Reciprocal	0.43063	57	2920.5	58	15988.0	53
46	Pareto 2	0.44683	58	3433.6	61	14174.0	52
45	Pareto	0.45639	59	3207.5	60	37297.0	56
35	Levy (2P)	0.46733	60	2807.0	57	21330.0	54
34	Levy	0.49549	61	3176.4	59	24292.0	55
8	Dagum (4P)	0.74542	62	17367.0	62	73164.0	57
12	Error Function	0.87905	63	40166.0	63	2.5959E+5	58
59	Student's t	0.99109	64	67012.0	64	6.0089E+6	59
65	Johnson SB	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Johnson SU [#31]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.00606 0.85365 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 0.44284 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	13 23.189 0.03946 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	16.985	19.812	22.362	25.472	27.688
Reject?	Yes	Yes	Yes	No	No

Normal [#44]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.0347 6.6286E-11 24				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	Yes	Yes	Yes	Yes	Yes
Anderson-Darling					
Sample Size Statistic Rank	10000 25.006 21				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	13 179.22 0 25				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	16.985	19.812	22.362	25.472	27.688
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
31	Johnson SU	g=-6.6105 d=5.3974 l=42.038 x=-23.12
44	Normal	s=14.737 m=43.369

Summary:

Johnson SU was the best-fit probability distribution function to the modelled tank yields in Brisbane (n = 1000; Kolmogorov-Smirnov statistic and P-value = 0.00606, 0.85, respectively; Chi-Squared statistic, DF and P-value = 23.189, 13, 0.04, respectively).

Moreton Bay

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	120.72
Mean	43.901
Variance	245.39
Std. Deviation	15.665
Coef. of Variation	0.35683
Std. Error	0.15665
Skewness	0.47567
Excess Kurtosis	0.42382

Percentile	Value
Min	4.6393
5%	20.393
10%	24.433
25% (Q1)	32.858
50% (Median)	42.916
75% (Q3)	53.5
90%	64.518
95%	71.452
Max	125.36

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
3	Burr (4P)	0.00647	1	0.50773	1	19.369	1
2	Burr	0.00685	2	0.54572	2	20.15	2
21	Gen. Extreme Value	0.0081	3	1.2118	10	29.763	11
31	Johnson SU	0.00812	4	0.91024	3	25.269	3
20	Gamma (3P)	0.00847	5	0.91902	4	27.179	7
23	Gen. Gamma (4P)	0.00861	6	0.92247	5	26.312	6
1	Beta	0.00864	7	0.93521	6	27.917	10
50	Pearson 6 (4P)	0.00877	8	1.0027	9	26.228	5
16	Fatigue Life (3P)	0.00879	9	0.96762	7	27.541	9
42	Lognormal (3P)	0.00883	10	0.9867	8	27.251	8
6	Chi-Squared (2P)	0.01064	11	3.0584	12	31.771	12
10	Erlang (3P)	0.01122	12	1.2561	11	26.192	4
53	Phased Bi-Weibull	0.01402	13	6.8523	15	53.573	15
62	Wakeby	0.01459	14	317.57	42	N/A	
43	Nakagami	0.01541	15	3.7146	13	37.349	13
38	Log-Logistic (3P)	0.01714	16	8.7416	16	73.67	17
7	Dagum	0.01955	17	5.1473	14	42.03	14

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
39	Log-Pearson 3	0.02039	18	69.073	34	N/A	
24	Gen. Logistic	0.02059	19	10.743	19	73.224	16
32	Kumaraswamy	0.02126	20	9.7469	17	80.432	18
63	Weibull	0.02154	21	16.408	22	103.12	21
64	Weibull (3P)	0.02182	22	10.015	18	82.725	19
19	Gamma	0.02464	23	13.044	20	108.39	22
44	Normal	0.02655	24	20.59	23	119.73	24
22	Gen. Gamma	0.02931	25	14.532	21	115.27	23
30	Inv. Gaussian (3P)	0.03034	26	29.781	26	89.073	20
49	Pearson 6	0.0357	27	23.706	25	179.93	27
11	Error	0.03718	28	23.235	24	146.9	25
18	Frechet (3P)	0.03917	29	36.054	28	299.97	29
58	Rice	0.0435	30	48.675	29	181.67	28
40	Logistic	0.04399	31	31.527	27	177.43	26
29	Inv. Gaussian	0.0462	32	72.12	35	427.73	33
26	Gumbel Max	0.04732	33	67.489	33	453.21	34
25	Gen. Pareto	0.05021	34	1793.6	52	N/A	
41	Lognormal	0.05363	35	61.196	32	415.99	32
37	Log-Logistic	0.05615	36	55.704	31	414.26	31
28	Hypersecant	0.05857	37	55.594	30	350.9	30
15	Fatigue Life	0.06357	38	82.578	36	487.21	35
36	Log-Gamma	0.06772	39	98.489	37	639.67	36
61	Uniform	0.07473	40	2045.6	56	N/A	
47	Pearson 5	0.08295	41	164.75	40	1126.6	38
33	Laplace	0.08616	42	119.21	38	812.39	37
4	Cauchy	0.09324	43	143.46	39	1658.9	42
27	Gumbel Min	0.09701	44	373.46	44	1333.3	41
51	Pert	0.10519	45	318.67	43	1891.7	43
56	Rayleigh (2P)	0.11652	46	273.56	41	1166.9	39
55	Rayleigh	0.11933	47	386.77	46	2207.2	45
5	Chi-Squared	0.12291	48	1082.6	50	4764.7	48
48	Pearson 5 (3P)	0.12403	49	423.49	47	2531.7	46
17	Frechet	0.12471	50	377.84	45	2075.6	44
9	Erlang	0.1505	51	551.24	48	1167.9	40
52	Phased Bi-Exponential	0.22915	52	1875.0	53	11005.0	50
60	Triangular	0.23095	53	937.5	49	3381.5	47
14	Exponential (2P)	0.29753	54	1649.5	51	9387.7	49
13	Exponential	0.32934	55	1913.8	55	11581.0	51
54	Power Function	0.33955	56	1910.8	54	N/A	
57	Reciprocal	0.40673	57	2688.2	57	15085.0	53
46	Pareto 2	0.43387	58	3372.3	61	13124.0	52
45	Pareto	0.44399	59	3138.2	60	34823.0	56
35	Levy (2P)	0.45919	60	2691.6	58	19744.0	54

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
34	Levy	0.4874	61	3061.6	59	22490.0	55
8	Dagum (4P)	0.75581	62	17072.0	62	73339.0	57
12	Error Function	0.85411	63	36441.0	63	2.3267E+5	58
59	Student's t	0.99158	64	66871.0	64	5.9107E+6	59
65	Johnson SB	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Burr (4P) [#3]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.00647 0.79338 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 0.50773 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	13 19.369 0.1121 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	16.985	19.812	22.362	25.472	27.688
Reject?	Yes	No	No	No	No

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
3	Burr (4P)	k=4.0438 a=3.4713 b=68.927 g=0.36771
44	Normal	s=15.665 m=43.901

Summary:

Burr (4P) was the best-fit probability distribution function to the modelled tank yields in Moreton Bay (n = 1000; Kolmogorov-Smirnov statistic and P-value = 0.00647, 0.79, respectively; Chi-Squared statistic, DF and P-value = 19.369, 13, 0.11, respectively).

Sunshine Coast

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	138.4
Mean	50.247
Variance	292.0
Std. Deviation	17.088
Coef. of Variation	0.34008
Std. Error	0.17088
Skewness	1.0331
Excess Kurtosis	2.2859

Percentile	Value
Min	15.722
5%	26.632
10%	31.026
25% (Q1)	38.584
50% (Median)	47.81
75% (Q3)	59.451
90%	71.864
95%	80.248
Max	154.13

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
3	Burr (4P)	0.0125	1	1.2281	1	54.663	1
2	Burr	0.01303	2	2.4533	2	64.729	2
62	Wakeby	0.01496	3	503.4	45	N/A	
7	Dagum	0.01622	4	4.1501	10	79.838	15
31	Johnson SU	0.01658	5	2.7277	4	76.789	11
38	Log-Logistic (3P)	0.0174	6	4.8362	13	95.193	18
21	Gen. Extreme Value	0.0175	7	2.7955	5	73.702	6
24	Gen. Logistic	0.01759	8	5.4593	17	77.985	13
48	Pearson 5 (3P)	0.01782	9	2.5166	3	68.848	3
42	Lognormal (3P)	0.01873	10	3.0443	6	70.784	4
16	Fatigue Life (3P)	0.01939	11	3.8119	8	74.806	9
30	Inv. Gaussian (3P)	0.0194	12	3.7206	7	72.308	5
22	Gen. Gamma	0.01943	13	6.1125	18	77.652	12
20	Gamma (3P)	0.01969	14	5.0515	14	75.129	10
23	Gen. Gamma (4P)	0.01976	15	4.2508	11	74.005	7
39	Log-Pearson 3	0.01986	16	3.8998	9	74.008	8
19	Gamma	0.02012	17	9.7731	22	98.652	19
1	Beta	0.02037	18	5.3749	16	78.411	14
49	Pearson 6	0.0206	19	4.672	12	87.526	17
50	Pearson 6 (4P)	0.02199	20	5.1143	15	80.093	16
37	Log-Logistic	0.02271	21	10.793	24	119.44	20
26	Gumbel Max	0.02428	22	10.048	23	136.82	25
29	Inv. Gaussian	0.02767	23	9.4155	21	123.1	22
18	Frechet (3P)	0.02803	24	9.0767	20	129.42	24
41	Lognormal	0.02879	25	8.7599	19	120.79	21
64	Weibull (3P)	0.03154	26	28.963	27	234.06	28
15	Fatigue Life	0.03198	27	11.095	25	128.04	23
36	Log-Gamma	0.03828	28	20.688	26	188.7	26

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
6	Chi-Squared (2P)	0.03882	29	29.949	28	204.47	27
32	Kumaraswamy	0.0472	30	59.436	31	413.62	31
56	Rayleigh (2P)	0.0489	31	52.965	30	379.17	30
47	Pearson 5	0.05068	32	40.31	29	319.93	29
25	Gen. Pareto	0.05606	33	2023.9	54	N/A	
44	Normal	0.06127	34	80.022	33	500.43	35
58	Rice	0.06156	35	86.412	35	601.47	38
63	Weibull	0.0642	36	101.66	36	498.69	34
40	Logistic	0.06516	37	69.823	32	414.0	32
43	Nakagami	0.06744	38	102.29	37	703.39	39
28	Hypersecant	0.07084	39	83.171	34	533.59	36
11	Error	0.08604	40	110.62	38	793.58	40
10	Erlang (3P)	0.08755	41	198.94	41	455.28	33
17	Frechet	0.09072	42	217.13	42	1067.5	42
61	Uniform	0.09543	43	2125.8	56	N/A	
4	Cauchy	0.09548	44	156.91	40	1536.0	43
33	Laplace	0.09572	45	136.17	39	969.37	41
9	Erlang	0.10673	46	255.69	43	581.18	37
51	Pert	0.11325	47	334.34	44	2034.3	44
27	Gumbel Min	0.13062	48	619.13	47	N/A	
5	Chi-Squared	0.13486	49	916.75	48	4426.3	46
55	Rayleigh	0.15978	50	563.43	46	3366.3	45
57	Reciprocal	0.23933	51	1267.7	50	9610.5	50
14	Exponential (2P)	0.2584	52	1229.1	49	6467.5	49
60	Triangular	0.30388	53	1636.5	51	4964.9	47
8	Dagum (4P)	0.31176	54	2087.5	55	5203.5	48
46	Pareto 2	0.34633	55	1987.1	53	14062.0	53
54	Power Function	0.34857	56	1955.0	52	12327.0	51
45	Pareto	0.35958	57	2215.2	58	16255.0	55
13	Exponential	0.36426	58	2128.3	57	13909.0	52
35	Levy (2P)	0.41225	59	2234.9	59	15130.0	54
52	Phased Bi-Exponential	0.46399	60	7318.6	61	25264.0	56
34	Levy	0.49757	61	3356.8	60	25920.0	57
12	Error Function	0.89596	62	40284.0	63	4.5289E+5	58
53	Phased Bi-Weibull	0.94255	63	36025.0	62	N/A	
59	Student's t	0.99799	64	70392.0	64	1.8642E+7	59
65	Johnson SB	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test):

Burr (4P) [#3]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.0125 0.08703 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	Yes	Yes	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 1.2281 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	13 54.663 4.6297E-7 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	16.985	19.812	22.362	25.472	27.688
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best and Normal Distributions:

#	Distribution	Parameters
3	Burr (4P)	k=2.4764 a=3.09 b=52.437 g=11.717
44	Normal	s=17.088 m=50.247

Summary:

Burr (4P) was the best-fit probability distribution function to the modelled tank yields in Sunshine Coast (n = 1000; Kolmogorov-Smirnov statistic and P-value = 0.0125, 0.09, respectively; Chi-Squared statistic, DF and P-value = 54.663, 13, 0, respectively).

Gold Coast

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	98.175
Mean	44.381
Variance	209.98
Std. Deviation	14.491
Coef. of Variation	0.32651
Std. Error	0.14491
Skewness	0.23348
Excess Kurtosis	-0.02851

Percentile	Value
Min	5.4383
5%	20.788
10%	26.071
25% (Q1)	34.61
50% (Median)	43.655
75% (Q3)	53.524
90%	63.768
95%	69.575
Max	103.61

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
42	Lognormal (3P)	s=0.08365 m=5.1497 g=-128.6
44	Normal	s=14.491 m=44.381

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
42	Lognormal (3P)	0.01006	1	1.5152	1	46.957	4
16	Fatigue Life (3P)	0.01024	2	1.5197	2	47.729	5
20	Gamma (3P)	0.01072	3	1.5679	3	46.494	2
50	Pearson 6 (4P)	0.01117	4	1.6016	4	46.161	1
31	Johnson SB	0.0129	5	1.8576	5	56.71	7
21	Gen. Extreme Value	0.01348	6	2.2132	8	52.986	6
1	Beta	0.01353	7	1.9952	6	57.569	9
2	Burr	0.01363	8	2.388	9	76.757	16
3	Burr (4P)	0.01372	9	2.3968	10	77.507	17
23	Gen. Gamma (4P)	0.01405	10	2.1498	7	64.078	12
62	Wakeby	0.01556	11	368.35	44	N/A	
43	Nakagami	0.01827	12	4.8609	11	57.055	8
38	Log-Logistic (3P)	0.01833	13	7.2536	14	58.15	11
10	Erlang (3P)	0.01918	14	6.2791	13	46.768	3
63	Weibull	0.01965	15	10.332	22	128.16	22
11	Error	0.02035	16	8.7601	19	94.835	19
44	Normal	0.02098	17	8.6548	18	91.999	18
6	Chi-Squared (2P)	0.02151	18	7.4852	16	71.479	13
64	Weibull (3P)	0.02169	19	7.2895	15	118.04	20
7	Dagum	0.02192	20	6.0279	12	74.956	14
32	Kumaraswamy	0.02206	21	7.5481	17	121.14	21
24	Gen. Logistic	0.02234	22	9.7075	20	76.133	15
30	Inv. Gaussian (3P)	0.0231	23	9.8569	21	57.686	10
39	Log-Pearson 3	0.0256	24	124.94	36	N/A	
19	Gamma	0.02789	25	26.245	25	162.17	24
49	Pearson 6	0.03237	26	28.687	26	165.0	25
22	Gen. Gamma	0.03329	27	29.276	27	173.87	26
53	Phased Bi-Weibull	0.03403	28	23.148	24	191.26	27
40	Logistic	0.03877	29	22.351	23	147.02	23
29	Inv. Gaussian	0.04796	30	92.804	32	401.19	31
28	Hypersecant	0.05276	31	47.216	28	293.87	29
58	Rice	0.05323	32	54.199	29	201.04	28
26	Gumbel Max	0.05533	33	110.99	33	486.58	33
41	Lognormal	0.05633	34	86.028	31	565.7	34
37	Log-Logistic	0.05673	35	71.374	30	457.86	32
25	Gen. Pareto	0.05957	36	2153.0	55	N/A	
36	Log-Gamma	0.06766	37	126.17	37	765.8	36
61	Uniform	0.06827	38	2004.2	53	N/A	

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
15	Fatigue Life	0.06913	39	111.14	34	653.06	35
9	Erlang	0.07728	40	136.5	38	392.35	30
33	Laplace	0.08091	41	112.26	35	805.6	37
51	Pert	0.08166	42	196.68	40	1223.5	38
4	Cauchy	0.08319	43	137.81	39	1397.0	41
47	Pearson 5	0.08977	44	199.64	41	1337.9	40
27	Gumbel Min	0.09117	45	287.57	42	1237.9	39
5	Chi-Squared	0.10419	46	769.43	50	3275.9	47
48	Pearson 5 (3P)	0.11795	47	363.06	43	2192.8	44
17	Frechet	0.12699	48	442.57	47	2255.1	45
56	Rayleigh (2P)	0.14741	49	392.66	45	1674.3	42
55	Rayleigh	0.14945	50	518.88	48	2991.8	46
60	Triangular	0.14961	51	425.43	46	1889.5	43
18	Frechet (3P)	0.16667	52	649.91	49	N/A	
52	Phased Bi-Exponential	0.26376	53	2479.0	56	13828.0	51
54	Power Function	0.30005	54	1572.6	51	9121.6	48
14	Exponential (2P)	0.31977	55	1781.1	52	10682.0	49
13	Exponential	0.34728	56	2078.3	54	13574.0	50
57	Reciprocal	0.4354	57	3087.3	58	14533.0	52
45	Pareto	0.44118	58	3160.3	59	35958.0	57
46	Pareto 2	0.46034	59	3660.7	61	15240.0	53
35	Levy (2P)	0.47519	60	2798.5	57	21985.0	54
34	Levy	0.50568	61	3202.8	60	25455.0	56
8	Dagum (4P)	0.59023	62	9005.9	62	25310.0	55
12	Error Function	0.87606	63	43607.0	63	2.9407E+5	58
59	Student's t	0.99207	64	67589.0	64	7.5986E+6	59
65	Johnson SU	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Lognormal (3P) [#42]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.01006 0.26145 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 1.5152 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	No	No	No	No

Chi-Squared					
Deg. of freedom Statistic P-Value Rank	13 46.957 9.8246E-6 4				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	16.985	19.812	22.362	25.472	27.688
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best and Normal Distributions:

#	Distribution	Parameters
3	Burr (4P)	k=2.4764 a=3.09 b=52.437 g=11.717
44	Normal	s=17.088 m=50.247

Summary:

Lognormanl (3P) was the best-fit probability distribution function to the modelled tank yields in Gold Coast (n = 1000; Kolmogorov-Smirnov statistic and P-value = 0.01006, 0.26, respectively; Chi-Squared statistic, DF and P-value = 46.957, 13, 0, respectively).

Ipswich

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	103.57
Mean	34.53
Variance	212.74
Std. Deviation	14.586
Coef. of Variation	0.42241
Std. Error	0.14586
Skewness	0.47194
Excess Kurtosis	0.37594

Percentile	Value
Min	0
5%	12.612
10%	16.561
25% (Q1)	23.73
50% (Median)	33.574
75% (Q3)	43.962
90%	53.327
95%	59.65
Max	103.57

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
3	Burr	0.01114	1	25.283	8	43.798	3
2	Burr	0.01114	2	25.283	7	43.798	2
22	Gen. Gamma	0.01167	3	25.999	9	55.035	6
58	Weibull	0.01299	4	27.061	10	36.572	1
21	Gen. Extreme Value	0.01488	5	2.2245	1	44.056	4
41	Nakagami	0.01573	6	27.077	11	55.182	7
31	Johnson SB	0.0164	7	2.5535	2	54.28	5
57	Wakeby	0.01676	8	527.15	43	N/A	
1	Beta	0.02235	9	5.5733	3	58.62	10
8	Dagum	0.02378	10	29.598	12	57.503	8

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
7	Dagum	0.02378	11	29.598	13	57.503	9
10	Erlang	0.02816	12	49.064	16	269.75	19
42	Normal	0.02848	13	19.305	5	100.84	12
59	Weibull	0.03176	14	46.006	15	148.91	15
50	Phased Bi-Weibull	0.03188	15	54.315	17	88.056	11
20	Gamma	0.03419	16	57.124	21	231.82	17
24	Gen. Logistic	0.03576	17	16.999	4	142.27	14
54	Rice	0.03612	18	59.924	23	130.52	13
11	Error	0.03806	19	24.367	6	172.33	16
46	Pearson 6	0.04219	20	55.297	18	284.25	22
47	Pearson 6	0.04236	21	55.442	19	281.32	20
19	Gamma	0.04245	22	55.584	20	286.44	23
23	Gen. Gamma	0.04352	23	57.138	22	283.79	21
36	Log-Logistic	0.04418	24	87.544	26	633.86	26
25	Gen. Pareto	0.0472	25	1806.7	53	N/A	
38	Logistic	0.04935	26	36.273	14	246.77	18
26	Gumbel Max	0.05002	27	73.387	25	480.49	25
30	Inv. Gaussian	0.05749	28	181.25	35	750.86	27
28	Hypersecant	0.06395	29	64.714	24	448.78	24
56	Uniform	0.06498	30	1922.5	54	N/A	
40	Lognormal	0.0735	31	136.65	28	864.72	31
39	Lognormal	0.07351	32	136.66	29	864.71	30
52	Rayleigh	0.07472	33	166.3	32	844.05	29
37	Log-Logistic	0.07903	34	150.39	30	980.79	33
16	Fatigue Life	0.0793	35	170.46	33	1062.2	35
15	Fatigue Life	0.0793	36	170.46	34	1062.2	36
33	Laplace	0.08532	37	134.2	27	977.42	32
48	Pert	0.08782	38	206.56	37	1245.6	39
53	Rayleigh	0.09108	39	201.0	36	789.17	28
4	Cauchy	0.09497	40	152.71	31	1786.8	40
27	Gumbel Min	0.09806	41	371.25	39	1206.2	37
29	Inv. Gaussian	0.09986	42	220.98	38	1208.0	38
44	Pearson 5	0.11751	43	378.72	40	2314.7	41
45	Pearson 5	0.11751	44	378.72	41	2314.7	42
9	Erlang	0.14133	45	460.68	42	1029.3	34
49	Phased Bi-Exponential	0.14417	46	903.31	46	7960.8	48
18	Frechet	0.15092	47	533.95	44	3100.9	43
6	Chi-Squared	0.15942	48	1532.2	50	6588.5	46
5	Chi-Squared	0.18304	49	1651.0	52	7226.8	47
17	Frechet	0.1862	50	670.83	45	5155.5	45
32	Kumaraswamy	0.25921	51	1211.7	47	4438.8	44
13	Exponential	0.28248	52	1527.2	49	8241.3	49
14	Exponential (2P)	0.28248	53	1501.9	48	8241.3	50

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
51	Power Function	0.31512	54	1636.4	51	9802.6	52
43	Pareto 2	0.38293	55	2774.0	57	9544.2	51
34	Levy	0.45014	56	2567.8	55	17492.0	53
35	Levy	0.45014	57	2567.8	56	17492.0	54
12	Error Function	0.7723	58	25973.0	58	1.3100E+5	56
55	Student's t	0.97733	59	60261.0	59	82724.0	55
60	Johnson SU	No fit					
61	Log-Gamma	No fit					
62	Log-Pearson 3	No fit					
63	Pareto	No fit					
64	Reciprocal	No fit					
65	Triangular	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test) and for the Normal Distribution:

Burr [#3]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.01114 0.16578 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	Yes	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 25.283 8				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	13 43.798 3.3140E-5 3				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	16.985	19.812	22.362	25.472	27.688
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
3	Burr	k=9.1654 a=2.713 b=85.456
42	Normal	s=14.586 m=34.53

Summary:

Burr was the best-fit probability distribution function to the modelled tank yields in Ipswich (n = 1,000; Kolmogorov-Smirnov statistic and P-value = 0.01114, 0.17, respectively; Chi-Squared statistic, DF and P-value = 43.798, 13, 0, respectively).

APPENDIX C: Fitting Probability Distributions to Modelled Overflow

Brisbane

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	239
Mean	61.779
Variance	1489.3
Std. Deviation	38.592
Coef. of Variation	0.62467
Std. Error	0.38592
Skewness	0.5672
Excess Kurtosis	-0.0586

Percentile	Value
Min	0.1
5%	6.2605
10%	13.38
25% (Q1)	31.61
50% (Median)	57.7
75% (Q3)	87.188
90%	114.82
95%	131.65
Max	239.1

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
61	Wakeby	0.00527	1	8.4747	5	N/A	
8	Dagum (4P)	0.01195	2	2.4523	1	37.665	1
7	Dagum	0.01446	3	3.1099	2	45.854	4
23	Gen. Gamma (4P)	0.01603	4	4.456	3	44.237	3
31	Johnson SB	0.02189	5	7.0242	4	40.922	2
63	Weibull (3P)	0.02638	6	20.914	8	172.84	8
50	Pert	0.0284	7	27.414	13	193.63	10
32	Kumaraswamy	0.02859	8	15.726	6	133.27	7
41	Lognormal (3P)	0.02885	9	26.278	11	193.91	11
21	Gen. Extreme Value	0.03132	10	17.165	7	81.956	5
55	Rayleigh (2P)	0.03205	11	21.387	9	121.93	6
18	Frechet (3P)	0.03337	12	31.132	16	251.51	18
49	Pearson 6 (4P)	0.03433	13	29.43	14	245.73	16
1	Beta	0.03442	14	21.713	10	175.92	9
3	Burr (4P)	0.03514	15	26.965	12	200.84	13
20	Gamma (3P)	0.03536	16	30.79	15	257.98	19
37	Log-Logistic (3P)	0.03568	17	41.694	17	342.16	22
38	Log-Pearson 3	0.03871	18	1478.6	54	N/A	
25	Gen. Pareto	0.04069	19	1557.1	55	N/A	
2	Burr	0.04091	20	42.861	18	289.91	20
24	Gen. Logistic	0.04196	21	46.91	19	250.14	17
42	Nakagami	0.04205	22	57.217	21	296.22	21
26	Gumbel Max	0.04704	23	64.413	24	450.83	24
6	Chi-Squared (2P)	0.04969	24	48.783	20	199.15	12
11	Error	0.05491	25	59.484	22	226.01	14
43	Normal	0.05499	26	60.838	23	234.74	15

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
62	Weibull	0.05625	27	89.66	25	711.3	27
19	Gamma	0.05871	28	154.91	30	768.63	30
60	Uniform	0.06329	29	2174.3	58	N/A	
39	Logistic	0.06683	30	93.565	26	432.18	23
48	Pearson 6	0.07317	31	109.17	27	659.52	25
54	Rayleigh	0.07412	32	217.72	33	1085.7	33
22	Gen. Gamma	0.07815	33	125.73	28	753.24	28
57	Rice	0.08222	34	238.21	34	1054.4	32
28	Hypersecant	0.08227	35	132.76	29	677.34	26
51	Phased Bi-Exponential	0.09108	36	383.56	38	2820.9	45
29	Inv. Gaussian	0.10716	37	1109.2	48	2398.0	39
33	Laplace	0.10834	38	216.81	32	1238.6	34
27	Gumbel Min	0.11365	39	457.4	40	1611.5	36
40	Lognormal	0.12034	40	340.46	37	2604.4	44
10	Erlang (3P)	0.12035	41	314.26	35	755.71	29
36	Log-Logistic	0.12058	42	316.52	36	2584.0	43
52	Phased Bi-Weibull	0.12126	43	397.82	39	1026.1	31
4	Cauchy	0.13151	44	197.4	31	1437.3	35
14	Exponential (2P)	0.15084	45	474.57	41	2411.0	40
13	Exponential	0.15124	46	478.35	42	2426.7	41
45	Pareto 2	0.15685	47	508.12	43	2494.2	42
59	Triangular	0.17376	48	556.29	44	1973.5	37
9	Erlang	0.19329	49	877.35	46	2363.1	38
17	Frechet	0.19637	50	861.56	45	6022.3	47
34	Levy	0.24883	51	1221.4	49	12420.0	53
46	Pearson 5	0.24993	52	1264.5	50	10977.0	51
53	Power Function	0.25734	53	1091.3	47	N/A	
47	Pearson 5 (3P)	0.26378	54	1390.8	53	12353.0	52
15	Fatigue Life	0.26611	55	1306.1	52	5739.7	46
16	Fatigue Life (3P)	0.29267	56	1581.6	56	6694.2	48
30	Inv. Gaussian (3P)	0.30657	57	1733.3	57	8194.6	49
5	Chi-Squared	0.32039	58	15113.0	62	25767.0	55
35	Levy (2P)	0.33419	59	1298.1	51	10125.0	50
44	Pareto	0.45239	60	3368.9	59	37853.0	56
56	Reciprocal	0.53503	61	5534.3	60	20187.0	54
12	Error Function	0.55047	62	11635.0	61	43038.0	57
58	Student's t	0.94201	63	63811.0	63	2.7389E+5	58
64	Johnson SU	No fit					
65	Log-Gamma	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test):

Wakeby [#61]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.00527 0.94249 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 8.4747 5				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
43	Normal	s=38.592 m=61.779
61	Wakeby	a=97.259 b=3.1296 g=48.301 d=-0.25032 x=-0.40328

Summary:

Wakeby distribution was the best-fit probability distribution function to the modelled tank overflows in Brisbane (n = 100; Kolmogorov-Smirnov statistic and P-value = 0.00527, 0.94, respectively; Chi-Squared test was not available to this distribution).

Moreton Bay

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	246.22
Mean	67.864
Variance	1889.5
Std. Deviation	43.468
Coef. of Variation	0.64052
Std. Error	0.43468
Skewness	0.5349
Excess Kurtosis	-0.20516

Percentile	Value
Min	0
5%	5.4705
10%	13.141
25% (Q1)	33.6
50% (Median)	63.55
75% (Q3)	97.37
90%	128.63
95%	145.77
Max	246.22

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
57	Wakeby	0.01051	1	4.9559	1	N/A	
7	Dagum	0.02098	2	34.182	6	63.24	4

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
8	Dagum	0.02098	3	34.182	7	63.24	3
22	Gen. Gamma	0.0235	4	36.163	8	54.522	2
31	Johnson SB	0.02555	5	7.565	2	52.845	1
48	Pert	0.03417	6	23.837	4	181.83	6
21	Gen. Extreme Value	0.03643	7	21.206	3	104.26	5
25	Gen. Pareto	0.03684	8	1415.7	47	N/A	
32	Kumaraswamy	0.03706	9	32.028	5	223.58	8
24	Gen. Logistic	0.04391	10	53.767	9	285.97	10
26	Gumbel Max	0.05074	11	73.268	13	525.7	17
2	Burr	0.05076	12	94.077	14	431.55	14
58	Weibull	0.05134	13	94.846	15	430.39	12
3	Burr	0.05138	14	94.956	16	431.3	13
41	Nakagami	0.0541	15	129.06	18	492.36	16
56	Uniform	0.05886	16	2138.0	51	N/A	
1	Beta	0.05892	17	66.416	12	357.93	11
11	Error	0.05911	18	58.79	10	199.17	7
42	Normal	0.05923	19	63.802	11	230.98	9
20	Gamma	0.06577	20	229.69	26	974.85	22
38	Logistic	0.07042	21	100.83	17	473.31	15
19	Gamma	0.0786	22	162.75	20	889.32	21
47	Pearson 6	0.07882	23	163.16	21	888.14	20
52	Rayleigh	0.08495	24	342.42	30	1554.7	30
28	Hypersecant	0.08589	25	142.73	19	739.89	18
49	Phased Bi-Exponential	0.0869	26	365.12	31	2606.0	38
50	Phased Bi-Weibull	0.08729	27	219.69	25	1486.2	28
23	Gen. Gamma	0.08833	28	195.11	22	996.2	23
46	Pearson 6	0.09262	29	209.71	24	829.35	19
54	Rice	0.09395	30	368.4	33	1438.8	26
53	Rayleigh	0.09395	31	368.4	32	1438.8	25
36	Log-Logistic	0.0947	32	247.67	28	1997.0	34
59	Weibull	0.10117	33	257.6	29	1704.0	32
10	Erlang	0.10908	34	517.22	41	1496.8	29
33	Laplace	0.11109	35	230.18	27	1317.4	24
27	Gumbel Min	0.11375	36	456.57	37	1633.5	31
30	Inv. Gaussian	0.11561	37	1638.6	50	2678.9	39
39	Lognormal	0.13314	38	468.1	38	3381.0	40
40	Lognormal	0.13314	39	468.12	39	3381.4	41
4	Cauchy	0.13619	40	204.47	23	1440.2	27
37	Log-Logistic	0.13781	41	487.97	40	3741.1	42
13	Exponential	0.14217	42	444.29	35	2201.0	35
14	Exponential (2P)	0.14217	43	416.47	34	2201.0	36
43	Pareto 2	0.14356	44	452.66	36	2244.8	37
9	Erlang	0.16618	45	662.48	42	1845.2	33

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
44	Pearson 5	0.21229	46	1184.1	45	7590.7	43
18	Frechet	0.21937	47	1110.4	44	7838.8	44
51	Power Function	0.22428	48	910.75	43	N/A	
16	Fatigue Life	0.25378	49	1480.3	49	14012.0	47
15	Fatigue Life	0.25378	50	1480.3	48	14012.0	46
17	Frechet	0.27863	51	1232.4	46	12441.0	45
6	Chi-Squared	0.33436	52	18857.0	57	28206.0	52
45	Pearson 5	0.34225	53	2219.8	52	22335.0	51
5	Chi-Squared	0.43757	54	20879.0	58	35589.0	53
34	Levy	0.44409	55	3543.2	53	18772.0	50
35	Levy	0.44409	56	3543.2	54	18772.0	49
29	Inv. Gaussian	0.48614	57	4573.4	55	16964.0	48
12	Error Function	0.53628	58	11056.0	56	40436.0	54
55	Student's t	0.93474	59	64281.0	59	2.5040E+5	55
60	Johnson SU	No fit					
61	Log-Gamma	No fit					
62	Log-Pearson 3	No fit					
63	Pareto	No fit					
64	Reciprocal	No fit					
65	Triangular	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test):

Wakeby [#57]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.01051 0.21803 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 4.9559 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
42	Normal	s=43.468 m=67.864
57	Wakeby	a=99.797 b=2.83 g=54.933 d=-0.26497 x=-1.6179

Summary:

Wakeby distribution was the best-fit probability distribution function to the modelled overflow in Moreton Bay (n = 1000; Kolmogorov-Smirnov statistic and P-value = 0.01051, 0.22, respectively; Chi-Squared test was not applicable).

Sunshine Coast

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	315.71
Mean	93.166
Variance	3200.7
Std. Deviation	56.575
Coef. of Variation	0.60724
Std. Error	0.56575
Skewness	0.45565
Excess Kurtosis	-0.27397

Percentile	Value
Min	0.07
5%	9.3805
10%	19.921
25% (Q1)	49.383
50% (Median)	88.45
75% (Q3)	131.32
90%	171.22
95%	194.1
Max	315.78

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
61	Wakeby	0.00879	1	4.7999	2	N/A	
8	Dagum (4P)	0.01395	2	3.4392	1	50.378	1
7	Dagum	0.02038	3	6.2691	3	71.724	3
52	Phased Bi-Weibull	0.02167	4	15.577	6	161.68	11
31	Johnson SB	0.02212	5	6.9063	4	57.729	2
23	Gen. Gamma (4P)	0.02541	6	9.7224	5	72.388	4
3	Burr (4P)	0.02682	7	21.08	11	180.77	13
63	Weibull (3P)	0.02697	8	23.106	12	198.02	16
41	Lognormal (3P)	0.02944	9	25.198	13	185.14	15
55	Rayleigh (2P)	0.03017	10	18.647	8	159.67	10
21	Gen. Extreme Value	0.03172	11	15.597	7	78.246	5
49	Pearson 6 (4P)	0.03198	12	29.707	15	251.47	19
20	Gamma (3P)	0.03214	13	29.825	16	250.41	18
32	Kumaraswamy	0.03265	14	20.208	9	148.02	9
18	Frechet (3P)	0.03304	15	34.163	17	314.26	21
50	Pert	0.03344	16	20.962	10	164.71	12
37	Log-Logistic (3P)	0.03571	17	39.434	19	288.39	20
1	Beta	0.03738	18	25.416	14	184.2	14
24	Gen. Logistic	0.03892	19	44.643	21	242.68	17
25	Gen. Pareto	0.04155	20	1599.1	53	N/A	
6	Chi-Squared (2P)	0.04711	21	37.393	18	133.04	7
11	Error	0.04896	22	39.636	20	126.17	6
10	Erlang (3P)	0.04989	23	68.043	24	397.55	23

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
43	Normal	0.04993	24	44.884	22	144.6	8
2	Burr	0.05059	25	63.723	23	402.41	24
26	Gumbel Max	0.05334	26	88.404	26	656.79	27
60	Uniform	0.05667	27	2146.6	57	N/A	
42	Nakagami	0.05683	28	105.6	27	531.27	25
39	Logistic	0.06064	29	79.795	25	365.98	22
38	Log-Pearson 3	0.06468	30	2431.1	58	N/A	
19	Gamma	0.06591	31	199.91	34	966.16	31
54	Rayleigh	0.07025	32	199.1	33	966.08	30
57	Rice	0.07573	33	206.47	36	922.8	29
28	Hypersecant	0.07598	34	119.16	28	626.57	26
62	Weibull	0.07634	35	156.18	30	1186.2	34
48	Pearson 6	0.08387	36	143.97	29	908.19	28
22	Gen. Gamma	0.09273	37	173.32	31	1003.3	32
51	Phased Bi-Exponential	0.09479	38	404.31	40	3092.0	42
33	Laplace	0.10157	39	201.99	35	1183.3	33
27	Gumbel Min	0.10541	40	399.06	38	1422.5	37
29	Inv. Gaussian	0.11002	41	1389.0	49	2488.1	38
59	Triangular	0.11258	42	241.36	37	1298.8	36
4	Cauchy	0.12654	43	182.56	32	1287.3	35
36	Log-Logistic	0.13478	44	401.16	39	3251.4	44
40	Lognormal	0.13484	45	423.55	41	3228.0	43
14	Exponential (2P)	0.16307	46	526.47	42	2790.1	39
13	Exponential	0.16327	47	528.14	43	2799.8	40
45	Pareto 2	0.19804	48	756.58	44	3064.6	41
17	Frechet	0.21402	49	992.15	46	7069.4	47
53	Power Function	0.23271	50	910.59	45	4548.3	46
9	Erlang	0.2352	51	1326.9	47	3548.0	45
34	Levy	0.26251	52	1479.2	50	14521.0	54
46	Pearson 5	0.27941	53	1517.2	51	13870.0	52
47	Pearson 5 (3P)	0.28119	54	1547.3	52	14059.0	53
15	Fatigue Life	0.31288	55	1770.0	54	7740.0	48
16	Fatigue Life (3P)	0.31834	56	1836.7	55	7930.7	49
30	Inv. Gaussian (3P)	0.33807	57	2066.1	56	9742.7	50
35	Levy (2P)	0.34222	58	1348.8	48	10914.0	51
5	Chi-Squared	0.34225	59	23243.0	62	29853.0	56
44	Pareto	0.46569	60	3485.7	59	30389.0	57
12	Error Function	0.56315	61	12387.0	61	47901.0	58
56	Reciprocal	0.57606	62	6819.0	60	23475.0	55
58	Student's t	0.95098	63	71791.0	63	2.7052E+5	59
64	Johnson SU	No fit					
65	Log-Gamma	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test):

Wakeby [#61]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.00879 0.42011 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 4.7999 2				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best-Fit and Normal Distributions Considered:

#	Distribution	Parameters
43	Normal	s=56.575 m=93.166
61	Wakeby	a=167.69 b=3.3178 g=71.713 d=-0.27383 x=-1.9685

Summary:

Wakeby distribution was the best-fit probability distribution function to the modelled tank overflows in Sunshine Coast (n = 1000; Kolmogorov-Smirnov statistic and P-value = 0.00879, 0.42, respectively).

Gold Coast

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	237.3
Mean	77.898
Variance	1986.5
Std. Deviation	44.57
Coef. of Variation	0.57216
Std. Error	0.4457
Skewness	0.45258
Excess Kurtosis	-0.36448

Percentile	Value
Min	1.63
5%	12.422
10%	20.701
25% (Q1)	43.065
50% (Median)	74.105
75% (Q3)	108.06
90%	140.07
95%	158.11
Max	238.93

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
62	Wakeby	0.00556	1	174.5	36	N/A	
23	Gen. Gamma (4P)	0.00888	2	0.74961	1	34.471	1
31	Johnson SB	0.01454	3	4.3509	3	59.321	3

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
8	Dagum (4P)	0.01458	4	3.7832	2	57.548	2
32	Kumaraswamy	0.01675	5	5.4342	4	73.944	5
1	Beta	0.01849	6	10.383	6	107.88	8
39	Log-Pearson 3	0.01853	7	20.609	12	N/A	
7	Dagum	0.02152	8	7.1191	5	62.069	4
51	Pert	0.02324	9	10.403	7	105.13	7
3	Burr (4P)	0.02537	10	15.987	8	143.82	9
64	Weibull (3P)	0.02572	11	17.37	11	150.98	11
21	Gen. Extreme Value	0.02572	12	16.429	9	84.513	6
56	Rayleigh (2P)	0.02898	13	16.874	10	145.68	10
2	Burr	0.0292	14	22.355	13	191.17	18
63	Weibull	0.03013	15	23.815	14	219.9	20
42	Lognormal (3P)	0.03049	16	25.368	16	179.84	14
30	Inv. Gaussian (3P)	0.03181	17	25.435	17	187.88	16
16	Fatigue Life (3P)	0.03217	18	25.622	18	189.76	17
50	Pearson 6 (4P)	0.03246	19	23.834	15	165.94	12
20	Gamma (3P)	0.03473	20	27.802	19	233.18	21
38	Log-Logistic (3P)	0.03506	21	40.951	22	298.44	23
25	Gen. Pareto	0.0379	22	1464.0	57	N/A	
18	Frechet (3P)	0.03926	23	35.469	20	301.31	24
24	Gen. Logistic	0.04028	24	48.228	24	251.37	22
6	Chi-Squared (2P)	0.04135	25	40.474	21	184.49	15
11	Error	0.04268	26	43.836	23	172.81	13
44	Normal	0.04507	27	50.952	25	214.81	19
43	Nakagami	0.04759	28	58.159	26	373.4	25
55	Rayleigh	0.0499	29	75.841	28	497.82	28
26	Gumbel Max	0.05176	30	83.324	30	607.93	31
58	Rice	0.05337	31	77.419	29	485.41	27
19	Gamma	0.05684	32	118.32	33	740.36	34
49	Pearson 6	0.05896	33	72.212	27	538.13	29
61	Uniform	0.06101	34	2183.2	58	N/A	
9	Erlang	0.06144	35	124.65	34	736.9	33
22	Gen. Gamma	0.06385	36	84.467	31	594.6	30
40	Logistic	0.06483	37	88.767	32	438.88	26
60	Triangular	0.07607	38	186.85	37	1111.3	36
28	Hypersecant	0.07969	39	130.55	35	702.89	32
10	Erlang (3P)	0.08285	40	267.71	42	910.42	35
41	Lognormal	0.09789	41	225.71	41	1735.1	41
29	Inv. Gaussian	0.09932	42	621.86	50	2045.8	42
37	Log-Logistic	0.09938	43	211.75	39	1669.4	40
52	Phased Bi-Exponential	0.1046	44	527.76	46	4239.0	49
33	Laplace	0.10681	45	218.07	40	1281.7	37
27	Gumbel Min	0.11094	46	402.59	44	1557.1	39

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
36	Log-Gamma	0.1229	47	361.3	43	2467.7	44
4	Cauchy	0.12421	48	193.65	38	1335.6	38
15	Fatigue Life	0.1511	49	437.12	45	2307.4	43
46	Pareto 2	0.16153	50	606.17	48	3302.0	47
47	Pearson 5	0.16795	51	604.09	47	4732.2	51
17	Frechet	0.16952	52	671.04	51	4329.9	50
14	Exponential (2P)	0.17158	53	620.52	49	3047.9	45
13	Exponential	0.17676	54	676.72	52	3295.2	46
48	Pearson 5 (3P)	0.19843	55	830.59	53	6509.4	52
54	Power Function	0.2236	56	888.67	54	4211.7	48
5	Chi-Squared	0.32075	57	15375.0	62	27278.0	56
34	Levy	0.34934	58	1400.3	55	10731.0	53
35	Levy (2P)	0.3538	59	1435.0	56	10747.0	54
45	Pareto	0.40337	60	2903.2	59	28237.0	57
57	Reciprocal	0.42719	61	3535.5	60	11532.0	55
12	Error Function	0.59385	62	13954.0	61	56889.0	58
53	Phased Bi-Weibull	0.81872	63	19304.0	63	88881.0	59
59	Student's t	0.97382	64	71188.0	64	1.0869E+6	60
65	Johnson SU	No fit					

Goodness of Fit Statistics for the Best-fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test):

Wakeby [#62]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.00556 0.91468 1				
☐	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 174.5 36				
☐	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
44	Normal	s=44.57 m=77.898
62	Wakeby	a=123.02 b=3.569 g=62.358 d=-0.31641 x=3.6026

Summary:

Wakeby distribution was the best-fit probability distribution function to the modelled tank overflows in Gold Coast (n = 1,000; Kolmogorov-Smirnov statistic and P-value = 0.00556, 0.91, respectively).

Ipswich

Descriptive Statistics:

Statistic	Value
Sample Size	10000
Range	159.52
Mean	39.16
Variance	844.1
Std. Deviation	29.053
Coef. of Variation	0.74191
Std. Error	0.29053
Skewness	0.67235
Excess Kurtosis	-0.06944

Percentile	Value
Min	0
5%	0.91
10%	3.723
25% (Q1)	14.82
50% (Median)	35.265
75% (Q3)	58.883
90%	79.42
95%	92.329
Max	159.52

Goodness of Fit Summary:

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
7	Dagum	0.0211	1	193.88	9	87.6	2
8	Dagum	0.0211	2	193.88	10	87.6	1
22	Gen. Gamma	0.02307	3	197.67	11	100.9	3
25	Gen. Pareto	0.02589	4	266.94	15	N/A	
57	Wakeby	0.02589	5	266.94	16	N/A	
31	Johnson SB	0.0495	6	22.93	1	105.4	4
21	Gen. Extreme Value	0.05856	7	51.525	2	264.28	5
49	Phased Bi-Exponential	0.05972	8	359.88	23	1563.5	27
26	Gumbel Max	0.06014	9	81.472	3	527.96	9
24	Gen. Logistic	0.06266	10	90.792	4	505.46	8
58	Weibull	0.06281	11	313.21	20	837.28	12
3	Burr	0.06295	12	313.11	19	843.29	15
2	Burr	0.06299	13	313.04	18	842.42	14
41	Nakagami	0.07388	14	380.36	24	839.42	13
48	Pert	0.0778	15	150.02	7	642.65	10
47	Pearson 6	0.07987	16	339.88	21	1084.7	18
19	Gamma	0.08013	17	340.36	22	1088.6	19
20	Gamma	0.0838	18	528.45	31	1441.5	25
38	Logistic	0.08415	19	157.91	8	672.68	11
42	Normal	0.08885	20	116.63	6	348.6	7
11	Error	0.0894	21	114.27	5	331.41	6
46	Pearson 6	0.09351	22	387.67	26	1045.9	17
32	Kumaraswamy	0.09376	23	567.47	33	N/A	
23	Gen. Gamma	0.09489	24	396.63	27	1272.6	22
14	Exponential (2P)	0.09951	25	222.42	13	1255.1	20
13	Exponential	0.09951	26	381.06	25	1255.1	21
28	Hypersecant	0.09962	27	204.49	12	981.82	16
36	Log-Logistic	0.10829	28	496.9	29	2677.8	30

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
56	Uniform	0.1109	29	2343.7	50	N/A	
43	Pareto 2	0.1186	30	448.92	28	1351.3	23
59	Weibull	0.12324	31	518.29	30	2703.1	31
33	Laplace	0.12495	32	299.73	17	1610.2	28
27	Gumbel Min	0.12904	33	570.3	34	1824.3	29
39	Lognormal	0.13906	34	678.77	36	3944.2	34
40	Lognormal	0.13906	35	678.78	37	3944.2	33
10	Erlang	0.13979	36	556.91	32	1457.7	26
52	Rayleigh	0.14489	37	1211.1	41	4424.8	38
30	Inv. Gaussian	0.1506	38	3933.8	54	4261.5	37
1	Beta	0.15849	39	867.98	39	N/A	
51	Power Function	0.16077	40	586.44	35	3887.4	32
37	Log-Logistic	0.16159	41	761.76	38	5051.7	39
4	Cauchy	0.16386	42	259.26	14	1382.5	24
54	Rice	0.16583	43	1336.1	43	4242.7	36
53	Rayleigh	0.16583	44	1336.1	44	4242.7	35
16	Fatigue Life	0.21467	45	1358.9	45	10444.0	43
15	Fatigue Life	0.21467	46	1358.9	46	10444.0	44
50	Phased Bi-Weibull	0.2232	47	1197.5	40	6130.9	40
18	Frechet	0.22859	48	1361.5	47	8946.5	42
17	Frechet	0.24895	49	1217.4	42	11036.0	45
45	Pearson 5	0.30727	50	2006.3	48	18454.0	50
44	Pearson 5	0.30727	51	2006.4	49	18444.0	49
9	Erlang	0.31543	52	2881.5	51	8039.8	41
6	Chi-Squared	0.33596	53	17789.0	57	26282.0	51
35	Levy	0.41877	54	3435.8	52	14066.0	47
34	Levy	0.41877	55	3435.8	53	14066.0	48
5	Chi-Squared	0.43696	56	18296.0	58	35232.0	53
29	Inv. Gaussian	0.45338	57	4350.1	55	13587.0	46
12	Error Function	0.5	58	8116.2	56	26627.0	52
55	Student's t	0.8684	59	48722.0	59	2.1821E+5	54
60	Johnson SU	No fit					
61	Log-Gamma	No fit					
62	Log-Pearson 3	No fit					
63	Pareto	No fit					
64	Reciprocal	No fit					
65	Triangular	No fit					

Goodness of Fit Statistics for the Best-Fit (i.e. rank #1 as per Kolmogorov-Smirnov Goodness of Fit test):

Dagum [#7]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.0211 2.6748E-4 1				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	Yes	Yes	Yes	Yes	Yes
Anderson-Darling					
Sample Size Statistic Rank	10000 193.88 9				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom Statistic P-Value Rank	13 87.6 4.0135E-13 2				
a	0.2	0.1	0.05	0.02	0.01
Critical Value	16.985	19.812	22.362	25.472	27.688
Reject?	Yes	Yes	Yes	Yes	Yes

Fitting Parameters of the Best-Fit and Normal Distributions:

#	Distribution	Parameters
7	Dagum	k=0.10772 a=7.1575 b=85.559
42	Normal	s=29.053 m=39.16

Summary:

Dagum distribution was the best-fit probability distribution function to the modelled tank overflow in Ipswich (n = 1,000; Kolmogorov-Smirnov statistic and P-value = 0.0211, 0, respectively).

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