Review of Rainwater Tank Cost-Effectiveness 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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Description: South East Queensland backyard with rain water tank
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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

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EXECUTIVE SUMMARY

This report provides an estimate of the cost-effectiveness of rainwater tanks in a number of Local Government Areas (LGAs) of South East Queensland (SEQ). The estimates drew upon recent research in the Urban Water Security Research Alliance which provided data about variables of cost and yield for rainwater tanks in the region. Probability distributions for the input variables were used to generate probability distributions for the levelised cost. The levelised cost is a measure of cost-effectiveness commonly used in the water and energy sector allowing an appropriate comparison of cost-effectiveness across a range of alternative investment options. This approach considers the physical flow of water as a revenue stream and assumes that the unit cost of water (the levelised cost) as well as the discount rate is constant over the period of analysis. Benefits such as deferred augmentation of the water supply for water authorities, reduced impact of water restrictions for the household and water sensitive urban design benefits for receiving waters were not included.

A summary of data, scenario and sensitivity assumptions for the study is shown in the following table. A ‘Basic Scenario’ was assumed to capture observed data and a long term government policy perspective with a 50-year period of analysis, a 3% discount rate based on government bond rates and maintenance based upon current practice. A weighted average levelised cost for SEQ was calculated based upon the number of houses and the levelised cost in each LGA. The rainwater tank cost-effectiveness in SEQ for this scenario was an average levelised cost of $9.22 per kilolitre (kL) with lower and upper limits of a 95% confidence of $6.73 and $12.77/kL. The variation in yield, pump and tank life and maintenance had the largest effect on the variation in the cost-effectiveness within a LGA.

Rainwater tank yield within a LGA was affected by the roof area, tank size and demand profile. The variability in each parameter resulted in a yield which was 16% lower than a yield calculated on average values. The calculation of yield based upon input distributions captured cases such as large roof area and tank size coupled with low water use (or demand) which resulted in lower tank yields and greater tank overflow.

The variation in rainfall across the SEQ region also had an effect on the cost-effectiveness of rainwater tanks. The Sunshine Coast was the most cost-effective location for a rainwater tank with an average levelised cost of $7.62/kL. Ipswich was the least cost-effective location for a rainwater tank with an average levelised cost of $11.17/kL. The distribution for Ipswich also had the highest skew and had a relatively high upper 95% confidence limit of $22.19/kL. Other LGAs considered fell within this range with Brisbane, Moreton Bay and the Gold Coast average levelised costs of $8.93, $8.97 and $8.90/kL respectively.

The cost-effectiveness results were sensitive to assumptions about the discount rate and tank maintenance. A doubling of the discount rate from 3% to 6% increased the mean levelised cost from $9.22/kL to $11.41/kL for the ‘Basic Scenario’. The effect of the discount rate was moderated by the discounting of both the operating costs and the yield. A change in maintenance from current to recommended practice led to a similar increase from $9.22/kL to $11.49/kL. The recommended practice addresses potential health risks which were not captured in the current maintenance.

An ‘Alternative Scenario’ was developed to provide a water utility perspective for the cost of capital with a 6% discount rate, a time frame for infrastructure appraisal of 25 years as well as maintenance according to recommended practice. The SEQ average levelised cost for this scenario was $14.11/kL with lower and upper 95% confidence limits of $10.27 and $19.62/kL.

The results of the analysis were not directly comparable to the results in Marsden Jacobs Associates (2007) *The cost-effectiveness of rainwater tanks in urban Australia* (MJA 2007). The MJA 2007 report considered the avoided cost to a household for purchasing water from the centralised water supply. In addition, there has been significant change in demand and end-use patterns in SEQ over the past six years. The MJA 2007 estimate of cost-effectiveness for a 5 kL rainwater tank in Brisbane was $2.29 and $5.47/kL for a 200 and 50 m^2 connected roof area respectively.

The variation in the results within an area with the same rainfall pattern suggests the potential to improve the performance of rainwater tanks. This is particularly true for the least cost-effective tanks within a region, with a large difference between the worst performance and the most likely performance in the region. Guidance for maintenance of rainwater tanks is also required to shift from current practice to recommended health guidelines.

In addition, both the upper and lower range were truncated by using a triangular distribution. This is particularly important for the upper range because of the skew in the distribution and may underestimate the least cost-effective tank. Additional sampling is required to determine the likelihood of very large values, which are currently considered as outliers, and to develop a more appropriate distribution. This, in turn, may suggest the need for quality control on the set-up of rainwater tanks to ensure expected performance in a given location.

Finally, some variables may not be independent and the current calculation of cost-effectiveness may require further analysis. For example, a high initial capital cost for a pump may be associated with a longer life and lower energy costs. This requires further data collection of cost and performance data which may also be useful to inform consumer choice.

Summary of Data, Scenario and Sensitivity Assumptions

	'Basic Scenario'			**'Alternative Scenario'**			**Sensitivity**
	Triangular Distribution			Triangular Distribution			
Financial	*min*	*most likely*	*max*	*min*	*most likely*	*max*	
Discount rate (%)		3			6		6 and 9
Period of analysis (years)		50			25		Same as 'Alternative Scenario'.
Capital and Installation ($AUD2012)							
Rainwater tank	1401	1544	1657	Same as 'Basic Scenario'			
Pump	722	790	962				
Plumbing	759	900	1017				
Tank installation	334	350	400				
Laying concrete slab	597	700	803				
Pump installation	200	250	300				
Operating, Maintenance and Replacement							
Energy							
Specific energy (kWh/kL)	1.1	1.48	1.9	Same as 'Basic Scenario'			
Unit cost for energy in 2012 ($/kWh)		0.2276					
Retail energy price path real growth rate (%)	3	5	7				
Useful lives (years)							
Pump life	5	10	15				
Rainwater tank life	15	25	35				
Plumbing		50					
Maintenance ($AUD2012)	0	20	54	54	104	184	Same as 'Alternative Scenario'
Yield (kL/year)							
Brisbane	18	42	76	Same as 'Basic Scenario'			Fitted distribution
Moreton Bay	16	43	78				
Sunshine Coast	24	48	90				
Ipswich	10	34	66				
Gold Coast	18	44	74				

1. INTRODUCTION

This report provides an estimate of the cost-effectiveness of rainwater tanks in South East Queensland (SEQ). The report follows previous estimates of cost-effectiveness estimates for rainwater tanks, in particular *The cost-effectiveness of rainwater tanks in urban Australia* (Marsden Jacob 2007). The MJA report drew upon available information at the time and suggested a large range in costs for the supply of water from rainwater tanks. Over the past five years, the UWSRA has undertaken research into the costs and performance of rainwater tanks in SEQ. This project draws upon recent data to provide an update of rainwater tank cost-effectiveness calculations for SEQ.

Rainwater tanks have been introduced in large numbers in SEQ over the past decade. Legislation such as the Queensland Development Code MP 4.2 has further encouraged their installation to meet development requirements to achieve a mains water savings target of 70 kL per household per year[1]. Rainwater tanks may also provide a number of functions including lessening the impact of water restrictions during times of drought. These 'level of service' implications as well as externalities associated with their production or use are not considered in this report. The report focuses on the cost-effectiveness of tanks for the provision of water.

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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).

2. METHOD

Data was reviewed to develop distributions for key variables for the calculation of cost-effectiveness. The cost-effectiveness calculation was undertaken in @RISK software (an application for Excel) which uses Monte Carlo simulation to generate a probability distribution of the cost-effectiveness and to undertake sensitivity analysis. A five kilolitre (kL) capacity internally plumbed rainwater tank was used as the basis for the calculations. The regions of Brisbane, Moreton Bay, Sunshine Coast, Ipswich and the Gold Coast were used to capture the geographic variation across SEQ.

2.1. Cost-Effectiveness

The cost-effectiveness of rainwater tanks was expressed in terms of the levelised cost. This approach considers the physical flow of water as a revenue stream and assumes that the unit cost of water (the levelised cost) as well as the discount rate is constant over the period of analysis. The analysis of levelised cost follows the approach outlined for the water and energy sectors (Fane, Robinson *et al.* 2002; OECD 2010)

Equation 1 outlines the general equation for the levelised cost of water supply.

$$\text{Levelised Cost} = \frac{C+\sum_{i=1}^{n} A_i/(1+r)^i}{\sum_{i=1}^{n} Y_i/(1+r)^i} \tag{1}$$

Where:

C = capital cost
A = annual costs
r = discount rate
Y = annual yield of water
i = year
n = period of analysis.

Each term in Equation 1 has a number of input variables. Capital includes the cost of the rainwater tank, the pump, laying of a concrete slab for the tank to rest upon as well as plumbing and installation of both the tank and the pump. Annual costs include operating costs such as energy use for the pump, maintenance costs such as desludging as well as capital replacement cycles for pumps and tanks over the period of analysis. The calculation of energy costs includes the specific energy of pumps as well as assumed price paths for electricity. Residual values of tanks and pumps were estimated as the fraction of the useful life of an asset remaining at the end of the period of analysis. For example, if the period of analysis was 30 years and the tank was replaced after 25 years, then only 20% of the value of the replacement tank was considered in the analysis.

A limitation of cost-effectiveness analysis is that a range of costs and benefits are not directly addressed. This limitation can be partly overcome by specifying a scenario that outlines how other costs and benefits are addressed. For example, rainwater tank maintenance may result in costs and benefits for human health. Specifying the health and maintenance requirements allows the cost for maintenance to be captured in the cost-effectiveness analysis as well as comparison with other studies with different assumptions. However, benefits such as deferred augmentation of the water supply for water authorities, reduced impact of water restrictions for the household and water sensitive urban design benefits for receiving waters were not included.

2.2. Financial Assumptions

A long term period of analysis of 50 years was assumed for the 'Basic Scenario' based upon the life of the plumbing which was the longest lived asset (Standard Australia 1999). The 'Alternative Scenario' and the sensitivity analysis also considered a 25-year period of analysis based upon the life of the rainwater tank and shorter periods of analysis common for infrastructure appraisals (for example (NSWTreasury 1999), (BlighTanner 2009) (CH2MHILL 2008). The two scenarios capture the assumptions for the period of analysis and life of assets from previous studies. For example, MJA (2007) assumed a 50-year useful life for a tank and a 50-year period of analysis. Gurung *et al.* (2012) assumed a 25-year life for a tank and a 50-year life for the plumbing.

A 3% discount rate was assumed to capture a government perspective of investment as well as long periods of analysis (Weitzman 2001; Weitzman 2007). A 3% discount rate reflects the *risk free* benchmark Weighted Average Cost of Capital (WACC) for the 2013-15 period for price monitoring of SEQ water and wastewater retail activities (Queensland Competition Authority, accessed 25 February 2013 http://www.qca.org.au/) which was based on the government bond rate (PWC 2013). A 6% and a 9% discount rate were also considered in the sensitivity analysis. A 6% discount rate reflects the current benchmark WACC which considers the cost of equity and debt for SEQ water utilities. A 9% discount rate provides an upper range discount rate that may be possible given the long period of analysis. The sensitivity analysis of the discount rates also provides insight into other investment perspectives. For example, MJA (2007) used the home loan interest rate of 8% to capture the household perspective of the investment at the time of the study.

Table 1 provides a summary of the financial assumptions for discount rates and period of analysis for three recent studies on the cost-effectiveness of rainwater tanks.

Table 1. Summary of Financial Assumptions for Rainwater tank Cost-effectiveness Studies.

Reference	Discount Rate: Base Rate	Discount Rate: Sensitivity	Period of Analysis
MJA 2007	8%		50
Stewart *et al.* 2011	7%	4, 6, 9	25
Gurung *et al.* 2012	7%	3, 11	50

2.3. Probability Distributions

Probability distributions were developed for input variables for the calculation of the cost-effectiveness. The probability distributions were used with software called @RISK (http://www.palisade.com/) to generate probability distributions of the levelised cost.

The approach adopted was based upon the International Panel on Climate Change (IPCC) recommendations for addressing uncertainty in data (IPCC 2000). A triangular distribution was assumed and defined by the most likely and upper and lower values for a 95% confidence interval. The triangular distribution based on a 95% confidence interval limits the effect of outliers while providing some weight to the tails of the distribution. This distribution was a pragmatic choice for relatively small sample sizes where a few unusual results may dominate the distribution. The triangular distribution can also be skewed and accommodates observations that the yield appeared to be positively skewed (Beal, Gardner *et al.* 2011). The Appendices provides further analysis of fitting distributions for yield modelled using the monitored data (Maheepala *et al.* 2013). A triangular distribution provides a rough approximation of the modelled yield distributions. A number of other distributions appear more appropriate based on the goodness of fit, although the highest ranked distribution varied between local government areas. Further research could define the distribution through better monitored data and an explanation of the underlying process that generates a particular distribution (for example see Limpert, Stahel *et al.* 2001 for an explanation of physical processes leading to log normal distributions).

The most likely value and the confidence interval were derived from recent studies which were reviewed in the following section. In general, the median was used to define the most likely value for the distribution. This was a pragmatic choice because the sample sizes were small for the cost data (1-10 data points) as well as yield monitoring (approximately 20 data points). In addition, the choice of samples for the yield calculation was not random but was based upon availability and aiming to capture areas with high growth and a geographic spread (Beal, Gardner *et al*. 2011; Chong, Mankad *et al*. 2011; Umapathi, Chong *et al*. 2012). This meant that the mode was difficult to calculate given that there were often only one of each value and the mean was potentially sensitive to outliers in the small samples.

3. REVIEW OF DATA

3.1. Geographic Coverage

A number of recent studies for rainwater tank performance in SEQ have focussed on the local government areas (LGAs) of the Gold Coast, Redlands, Caboolture and Pine Rivers (now part of the Moreton Bay Regional Council) (Beal, Gardner *et al.* 2011; Chong, Mankad *et al.* 2011; Chong, Umapathi *et al.* 2011; Umapathi, Chong *et al.* 2012). Figure 1 shows the SEQ council areas including those selected in the recent studies. The use of the same three Local Government Areas has allowed different methods to be cross checked as well as explain different factors affecting the results. It was also noted that these areas capture about 40% of the number of people in SEQ and have high growth rates (Beal, Gardner *et al.* 2011). This meant that a number of assumptions were required to use the monitored data to construct an average for the region.

A rough distribution of existing and new tanks across SEQ was estimated based upon the existing and planned dwellings in the Regional Plan (QG 2009). The cost-effectiveness and the number of dwellings in each local government area was used to estimate a weighted average for rainwater cost-effectiveness in SEQ. Table 2 provides a summary of the weightings based upon the fraction of dwellings in each LGA as well as the assumptions for LGAs not considered in the monitoring and modelling. The proportion of tanks in each LGA does not change much over the next 20 years although some areas experience large growth.

Table 2. Assumed proportion of the total number of water tanks in each Local Government Area.

Local Government Area	Proportion of SEQ Houses in 2006	Proportion of SEQ Houses in 2031
Brisbane	0.35	0.29
Gold Coast	0.18	0.18
Sunshine Coast	0.12	0.12
Moreton Bay	0.11	0.11
Logan+	0.08	0.09
Redland*	0.04	0.04
Ipswich	0.05	0.09
Western councils+	0.03	0.04
Toowoomba+	0.04	0.04
	1.00	1.00

\+ the performance of Ipswich LGA was assumed for these LGA
* the performance of Brisbane LGA was assumed for this LGA

In addition, practical constraints for monitoring households meant that samples were small and based more upon availability and typical households in targeted areas rather than random selection across the region. This means that the average or median from each study may be partly due to differing samples. For example, the Caboolture area of Moreton Bay Regional Council was not included in one study due to data availability (Beal, Gardner *et al.* 2011). Conversely, detailed monitoring of 20 households selected 12 of the sites in Moreton Bay Regional Council (8 monitoring site in Pine Rivers and 4 in Caboolture) and 8 monitoring sites for Redlands and the Gold Coast. The small samples also mean that the distribution is sensitive to a couple of large values or ‘outliers’.

Figure 1. **South East Queensland Council Areas (Chong, Umapathi *et al.* 2011).**

3.2. Capital Costs

Table 3 presents a comparison of parameters for two surveys of rainwater tank capital and installation costs (Gurung, Sharma *et al.* 2012) and (Marsden Jacob 2007). The survey from 2007 was expressed in 2012 values using an average annual inflation rate of 3.1% for the period based upon the Reserve Bank of Australia's inflation calculator (<http://www.rba.gov.au/calculator/annualDecimal.html> accessed 14 Nov 2012). Each survey had a relatively small number of samples. Items such as rainwater tanks capital cost had a relatively small standard deviation which may reflect a mass produced homogenous product and a competitive market. Pumps had a higher variation in cost which may reflect a less standardised product. Other items such as plumbing and laying concrete slabs had a higher variation which presumably reflects differing on-site conditions and perhaps variation in the demand and supply of labour.

Average costs for the 2007 survey fall outside of the 95% confidence interval of the 2012 survey in most cases and suggests a statistically significant difference between the survey results. However, establishing 'statistical significance' is itself questionable given the small number in each sample and little detail about the surveys themselves. For example, the 2007 survey did not explicitly include 'incidentals' such as laying a concrete slab and pump installation. If these items were included based upon the 2012 survey, then the average total capital and installation costs for both surveys was approximately $4,600 despite differences for each cost component. Further data collection is required to improve the confidence in the costs, particularly for cost categories such as plumbing and tank installation costs which appeared to be lower in the 2012 study than in 2007.

A triangular distribution was assumed with the minimum and maximum based on the upper and lower limits of a 95% confidence interval and the most likely value based upon the median.

Table 3. Comparison of Survey Capital and Installation Costs for 5kL Rainwater Tanks.

Reference	Parameter	Rainwater Tank Cost ($2012)	Pump Cost ($2012)	Plumbing Costs ($2012)	Tank installation Costs ($2012)	Laying Concrete Slab ($2012)	Pump installation ($2012)	Total (2012)
(Gurung, Sharma *et al.* 2012)	Average Cost:	1529	842	888	367	700	250	4576
	median	1544	790	900	350	700	250	
	standard deviation	207	194	131	29	117	*	
	n	10	10	4	3	5	1	
	95% CI	128	120	129	33	103		
	upper 95% limit	1657	962	1017	400	803		
	lower 95% limit	1401	722	759	334	597		
(Marsden Jacob 2007)	Average Cost:	1270	729	1067	639			3706
	median	1276	728	889	638			
	standard deviation	136	261	1008	243			
	n	14	18	8	4			
	95% CI	71	121	698	238			
	upper 95% limit	1341	850	1765	877			
	lower 95% limit	1199	609	369	401			

* a variation of +/- 20% was assumed based upon the variation in the pump costs with the only value available assumed as the most likely.

3.3. Operating Costs

3.3.1. Energy Price Path and Carbon Price Assumptions

The Queensland Competition Authority (QCA) provides determinations for electricity prices in Queensland. This considers factors such as network, energy and retail costs and setting appropriate returns on investment. However, the current government introduced a price freeze for 2012-13 retail electricity prices and the QCA will make a ‘cost reflective’ determination for the 2013-2016 period (QCA 2012).

Capital and operating expenditure for retail electricity in Queensland up to 2013/14 has been estimated by the Australian Electricity Market Commission (AEMC). The AEMC noted that, without a price on carbon, the 2010/11 retail price for electricity was $0.2069 per kilowatt hour (kWh) and was expected to increase by about 32% to $0.2736/kWh in 2013/14 in Queensland (AEMC 2011). The average growth rate over the three-year period was about 10%. Over the same period with a price on carbon, the retail electricity price was expected to increase by about 42% with an annual growth rate of 12% (AEMC 2011). High growth rates for electricity prices were also noted by Stewart (2011) who noted a 7.3% inflation rate for electricity prices based on the change in electricity prices in the five years prior to 2011. A report to the Australian Energy Market Operator outlined a number of 20-year scenarios which captured a range of economic conditions and carbon price scenarios. Wholesale electricity prices for Queensland rose by 3, 5 and 7 times the current price over the 20-year period for the various scenarios which give growth rate of about 3.8%, 5.5% and 6.7% respectively (IES 2010). In summary, the analysis assumes a triangular distribution for growth rates for electricity prices with a minimum, most likely and maximum value of 3%, 5% and 7% respectively. A retail electricity price in Queensland for 2012 of $0.2276/kWh was assumed as a starting price base (Gurung, Sharma *et al.* 2012).

3.3.2. Specific Energy

Recent studies have reported the average and the range for specific energy (energy use per unit of water flow) for rainwater tank pumps (Retamal, Glassmire *et al.* 2009; Ferguson 2012; Umapathi, Chong *et al.* 2012). Monitoring of tank performance was undertaken in two main geographic areas – namely Sydney and SEQ – and the specific energy is unlikely to vary geographically. Table 4 provides a summary of the surveys of rainwater tank specific energy.

The three main studies all present an average specific energy of about 1.5 kilowatt hours per kilolitre (kWh/kL). However, this may be coincidental given that the samples were not random, the number of data points was small in two surveys and all studies reported a very large range. A large component of the range was attributed to the selection of a pump to match the low flow rate of demands on the rainwater tank. For example, Ferguson (2012) noted that pump selection alone could change the specific energy from 0.7 to 2.4 kWh/kL. The specific energy of 0.7 kWh/kL appears to provide a reasonable minimum energy intensity. However, a reasonable upper range value was more difficult to define and may be very high (Beal, Hood *et al.* 2008; Lane and Gardner 2009) although less common. Umapathi *et al.* (2012) also presented the specific energy for 'trickle top-up' and automatic switching devices as 1.59 and 1.46 kWh/kL respectively. Although there may be technical reasons to expect a difference, the sample size was small (about 10 of each) and the difference relatively small compared to the range within each category.

Table 4. Specific Energy for Rainwater Tank Pumps.

Reference	Sample no.	Average (kWh/kL)	Median (kWh/kL)	SD	Range*
Retamal (2009)		1.5			0.9-2.3
Umapathi *et al* (2012)	19	1.52	1.48	0.45	0.75-2.1 Lower 95% Confidence Interval limit 1.1 kWh/kL Upper 95% Confidence Interval limit 1.9 kWh/kL
Ferguson (2012)	52	1.5			0.7-3

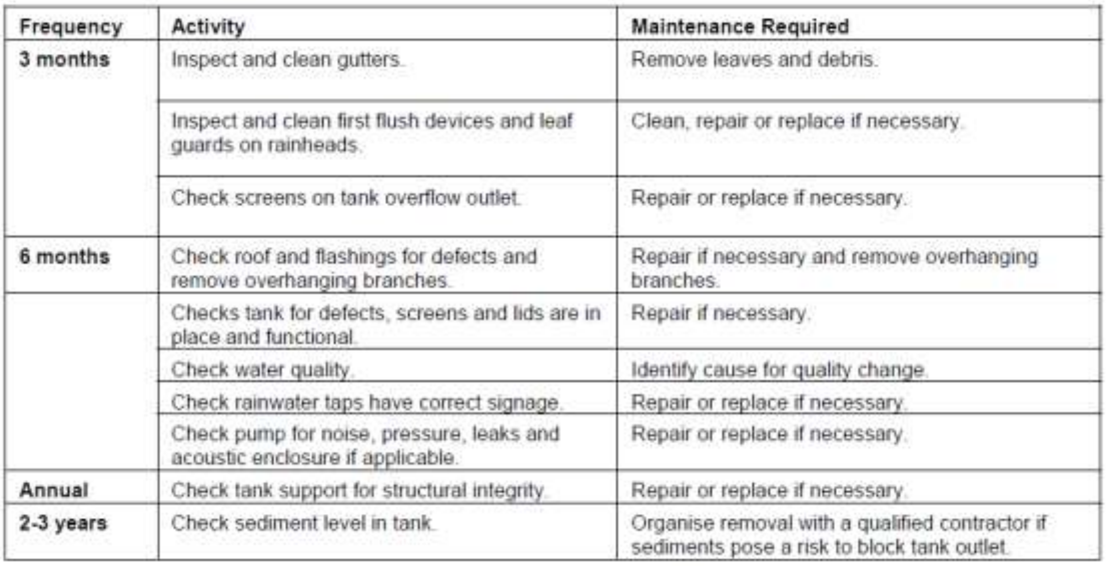
* The range reported in the table excludes the 'outliers' at either end of the range.

3.3.3. Maintenance

The quantification of maintenance costs first needs to distinguish between 'current practice' and 'good practice'. For example, a survey of rainwater tank maintenance in SEQ indicated that relatively few respondents checked for the build up of sediment in the tank and even less removed it as required (Mankad, Tucker *et al.* 2012). Tanks installed as part of mandatory requirements were less likely to be maintained than voluntary installations (Mankad, Tucker *et al.* 2012). These results follow earlier research in SEQ that indicated that 'half of the owners of required tanks reported that they never cleaned their screens and gutters or inspected inside their tanks or did so only when there were obvious problems' (Gardiner 2010). These observations suggest that minimal maintenance is not only current practice but also the 'most likely' scenario unless there is guidance for household tank maintenance practices. Possible policy approaches for rainwater tank maintenance are discussed in detail in Walton *et al.* 2012. A nominal maintenance of $20 per year was assumed similar to MJA (2007). A triangular distribution was assumed with the lower 95% limit with no maintenance and the upper limit of $54 per year to reflect minimal maintenance of sediment checking and cleaning. Any effect upon tank performance from poor maintenance was assumed to be captured by current monitored data. However, perhaps of greater concern are any health impacts from poor maintenance which were not considered in the study.

An alternative maintenance scenario was also developed for 'good practice' and considered in the sensitivity analysis. Table 5 presents the recommended inspection and maintenance for rainwater tanks based upon Queensland Health Guidelines (Moglia, Tjandraatmadja *et al.* 2011).

Table 5. Recommended inspection and maintenance for rainwater tanks based on Queensland Health guidelines (Moglia, Tjandraatmadja *et al.* 2011).



Frequency	Activity	Maintenance Required
3 months	Inspect and clean gutters.	Remove leaves and debris.
	Inspect and clean first flush devices and leaf guards on rainheads.	Clean, repair or replace if necessary.
	Check screens on tank overflow outlet.	Repair or replace if necessary.
6 months	Check roof and flashings for defects and remove overhanging branches.	Repair if necessary and remove overhanging branches.
	Checks tank for defects, screens and lids are in place and functional.	Repair if necessary.
	Check water quality.	Identify cause for quality change.
	Check rainwater taps have correct signage.	Repair or replace if necessary.
	Check pump for noise, pressure, leaks and acoustic enclosure if applicable.	Repair or replace if necessary.
Annual	Check tank support for structural integrity.	Repair or replace if necessary.
2-3 years	Check sediment level in tank.	Organise removal with a qualified contractor if sediments pose a risk to block tank outlet.

Table 6 presents the maintenance costs for individual rainwater tanks from a recent study (Gurung *et al.* 2012). Based upon these activities, the maintenance costs for recommended practice was $184 per year assuming all tasks were outsourced or $104 per year assuming the household performs tasks such as gutter maintenance. A triangular distribution was assumed with minimum, most likely and maximum value of $54, $104, $184 per year respectively. This assumes a recommended practice scenario with 'most likely' capturing a reduced cost recommended maintenance.

Table 6. Maintenance costs for an individual rainwater tank system (Gurung *et al.* 2012).

Component	Frequency	Average Cost	Average Cost Per Year
Sediment Check/ Cleaning	Three Years	$162	$54
Gutter Maintenance, etc	Annually	$80	$80
Check Signage, pumps, filters, water quality	Annually	$50	$50
			$184

3.3.4. Replacement Cycles and Useful Lives

Replacement cycles were based upon estimates from a number of studies. One study noted that results can be sensitive to a reduction in tank replacement from 25 to 15 years and pump replacement from 15 to 10 years (Stewart 2011 - p3). The cost associated with replacement considered the residual value of the asset at the end of the period of analysis. The residual value was estimated as the fraction of useful asset life remaining. For example, assuming a 30-year period of analysis and a useful life of a tank of 20 years then only half of the value of the replacement tank would be considered in the analysis.

Table 7 presents the assumed useful life and distribution for rainwater tank components. The literature provided estimates and possible ranges but did not provide data to calculate a distribution.

Table 7. Useful life of rainwater tank components.

Component	Useful Life (years)				Notes on the Range and the Assumed 95% Confidence Interval
	Gurung	Stewart	Stewart sensitivity	MJA	
Rainwater Tank (PVC)	25	25	15	50	Stewart 2011 p49, p65 notes that rainwater tanks have a structural guarantee for 25 years but there is anecdotal evidence that poor quality tanks have shorter life spans. This suggests that some good quality tanks may also last longer than 25 years. MJA 2008 appears to assume a 50 year life (MJA Appendix 2). A triangular distribution was assumed based upon a minimum, most likely, and maximum value of 15, 25, 35 years.
Household Plumbing	50				
Domestic pump	10	15	10		Stewart 2011 p49, p65 notes a range of 5-15 years for pump and switch systems. MJA p21 assumed 10 years with a caveat that suppliers noted that cheaper pumps may last 'considerably less' than 10 years. A triangular distribution was assumed based upon a minimum, most likely, and maximum value of 5, 10, 15 years.

3.4. Yield

Rainwater tank yield was modelled separately and described in Maheepala *et al.* 2013. Table 8 provides a summary of the parameters for the tank yield distribution assumed for calculating the cost-effectiveness. The triangular distribution was assumed using the histogram of yield from Maheepala *et al.* 2013 to define the minimum, most likely and maximum values. A 95% confidence interval was assumed to define the minimum and maximum and the median was used for the most likely value. This distribution captured the apparent skew in the yield results as well as simplified assumptions about the yield distribution.

Table 8. Assumed distribution parameters for tank yield.

	Tank Yield (kL/hh/yr)		
Local Government Area	**Minimum**	**Most Likely**	**Maximum**
Brisbane	18	42	76
Moreton Bay	16	43	78
Sunshine Coast	24	48	90
Ipswich	10	34	66
Gold Coast	18	44	74

The modelled results were also compared to previous estimates of yield including recent monitoring and analysis of billing data. Note that the modelled data drew upon the monitored data but considered stochastic performance based upon distributions of rainfall, roof area and assumed end use as well as effects from up-scaling of rainwater tanks.

3.4.1. Review of Yield Estimates and Recent Monitoring and Billing Analysis

The variability in rainfall, end use and demand, not to mention assumptions about occupancy and connected roof area, make it difficult to compare current and past yield estimates. For example, average daily water consumption in the SEQ region in 2008 was almost half of the 2005 value used in the rainwater tank modelling on which the QDC MP 4.2 target of 70 kL/household/yr (kL/hh/yr) was based (Beal, Gardner *et al.* 2011 – p23). Nonetheless, modelling for the QDC MP 4.2 also produced a large range in yield from 52-133 kL/hh/year (Beal, Gardner *et al.* 2011 - p5).

MJA (2007) calculated a yield ranging from 41-99 kL/hh/yr for a 5 kL tank in Brisbane with connected roof area of 50 and 200m^2 respectively (MJA 2007 - pESvi). A 'base case' yield of 71 kL/hh/yr was also calculated with the connected roof area having greatest effect on the yield and potentially varying the yield from 36 to 90 kL/hh/yr. The base case assumed a property with 125m^2 roof connected, 5 kL tank and average 2.4 occupants, and a location with an average rainfall of 900 mm and a temperate climate (MJA 2007 – pESiv).

The recent research on tank yields has a stronger focus on measuring rather than modelling (Beal, Gardner *et al.* 2011; Chong, Mankad *et al.* 2011; Umapathi, Chong *et al.* 2012). This may reflect the opportunity to observe actual performance from the many tanks installed over the intervening period. Beal *et al.* 2011 analysed over 1100 data pairs for council billing for water consumption for houses with and without an internally plumbed rainwater tank (IPT) (Beal, Gardner *et al.* 2011). The sample population was likely to be 'typical' but not necessarily representative of the mandated rainwater tank population in SEQ. The regions were chosen because of the availability of data and high growth rates and included the Sunshine Coast Regional Council, Moreton Bay Regional Council, Redland City Council and Gold Coast City Council. These areas capture 40% of the number of people in SEQ and their high growth rates suggests a higher proportion of new tanks than more established areas such as Brisbane City Council (which was not included in the sample). The same Council areas were used by Chong, Umapathi *et al.* (2011) in a study that refined the statistical analysis by normalising for occupancy and also considered data for 2009 and 2010. Both studies reported the mean and median for each region. Based upon Chong, Umapathi *et al.* 2011 data for each Council area, the distribution appeared to have a slight positive skew and the mean was greater than the median. Beal *et al.* 2011 noted that the distribution of water consumption was also positively skewed which suggests the use of the median to describe typical performance (Beal, Gardner *et al.* 2011). However, calculating an average for SEQ based on the Council areas was problematic because of the question of sample representativeness (regardless of whether Council area means or medians were used). In fact, based upon the four council areas, it could be argued that the distribution was bimodal because there were two high and two low values and no value similar to the mean or median.

Table 9 provides a summary of the yield estimates in SEQ. Note that Beal *et al.* 2011 also performed cross checks on the statistical analysis by considering modelled yields as well as yields based on the demand met by the rainwater tank.

The median rainwater tank yield ranged from 28-52 kL/hh/yr with an average of the median value of 40 kL/hh/yr across the regions considered (Beal, Gardner *et al.* 2011). The yields were 28, 41 and 52 kL/hh/yr for Pine Rivers, Redlands and the Gold coast. This also suggests that the mean of the medians was not weighted and did not consider other LGAs in SEQ.

The statistical analysis was refined by Chong, Umapathi *et al.* (2011 p25) by normalising for occupancy. However, the same four Council areas were considered and the representativeness to the region was not considered. The reported average annual mains water savings per household per year across the four LGAs in 2009 was estimated at 58.8 kL/hh/yr, ranging from 24.5 kL/hh/yr (Pine Rivers) to 88.5 kL/hh/yr (Gold Coast). The estimate was based on a survey of billing information for mains water consumption for similar households with and without rainwater tanks.

Table 9. Review of Rainwater Tank Yields for a 5kL Internally Plumbed Tank in SEQ.

			Average Savings per IPT Household Per Year (kL/hh/yr)				
Study	**Type of Analysis**	**Central Tendency Measure**	**Pine Rivers**	**Caboolture**	**Gold Coast**	**Redland**	**Range**
Chong *et al* 2011	Billing data for 2009	Mean	25	37	89	84	
Chong *et al* 2011	Billing data for 2010	Mean	40	41	81	71	
Beal *et al* 2011	Billing data 2008	Mean	20		95	33	
Beal *et al* 2011	Billing data 2008	Median	28		52	41	
Beal *et al* 2011	End use with 2008 data?						43-46
Beal *et al* 2011	Modelling with 2008 data		49		54	46	
MJA 2007	Modelling with 2006 data?						41-99
WBM 2006*	Modelling with 2005 data						52-133

There was also a difference in the estimate of yield depending on the use of the mean or median. In general, the median is a more accurate measure of central tendency than the mean for skewed distributions. For example, Beal (p1 2011) noted that the distribution of water consumption was positively skewed which suggests the use of the median (because the mean will be an overestimate of the central tendency). Chong, Umapathi *et al.* (2011) reported that the mean was ‘more relevant for comparison with the published SEQ regional average water consumption data’.

Beal notes that the ‘Statistical analysis results were cross-checked with two other approaches used to estimate mains water savings from IPT. Firstly, water consumption from the IPT-sourced toilet and cold water laundry tap were calculated using measured water end use data from recent SEQ residential end use research (Beal *et al.* 2011; Willis *et al.* 2011). Results from these calculations demonstrated that an average savings of 44 kL/hh/yr could be expected from offsetting mains toilet and laundry supply alone.

Secondly, the Rainwater TANK model showed that predicted rainwater use for allowable internal uses ranged from 46 to 54 kL/hh/yr, at an average 50 kL/hh/yr, for a 5 kL tank connected to $100m^2$ roof area and using the 2008 climate data for each council. Therefore, the baseline mains water savings one could expect is between 44 and 50 kL/hh/yr from internal water usage only.’

Chong, Mankad *et al.* (2011, Phase 1- p11) reported very similar ‘inferred’ roof area for each of the four LGAs, suggesting that differences in roof area between the four LGAs was not a major driver for yield variability across the LGAs. However, Chong, Umapathi *et al.* (2011, Phase 2- p2) also noted that the variations in water savings from internally plumbed rainwater tanks ‘could be driven by factors such as rainwater tank yield factors related to climate and roof area connectivity, socio-demographic factors (WaterWise awareness and water use behaviour in the household) and the use of water efficient household appliances and fixtures’.

Chong, Umapathi *et al.* (2011, Phase 2 Table 3 p17) also reported the water savings also appeared to reflect the household water consumption. Households with high water consumption gained greater yields from the rainwater tanks. For example, the Gold Coast area has the highest water consumption and the greatest saving from the rainwater tanks. Conversely, Pine Rivers had one of the lowest consumptions and lowest yield. Interestingly, Caboolture had the lowest consumption but not the lowest rainwater tank yield. This may reflect the effect of rainfall in the different regions. Chong (2011, Phase 2 p23) noted that the Gold Coast region didn’t experience severe outdoor water restrictions whereas Pine Rivers did during 2008.

3.5. Summary of Assumptions

Table 10 provides a summary of the assumptions for the data based upon the review of recent studies. Two scenarios were developed to capture different combinations of the data for the analysis. A ‘basic scenario’ was developed to reflect current practice and the sensitivity of the results explored for a range of variables. An ‘alternative scenario’ was then developed to capture maintenance based upon recommended practice as well as a shorter period of analysis and a higher discount rate.

Table 10. Summary of Data, Scenario and Sensitivity Assumptions.

	‘Basic Scenario’			**‘Alternative Scenario’**			**Sensitivity**
	Triangular Distribution			Triangular Distribution			
Financial	*min*	*most likely*	*max*	*min*	*most likely*	*max*	
Discount rate (%)		3			6		6 and 9
Period of analysis (years)		50			25		Same as ‘Alternative Scenario’.
Capital and Installation ($AUD2012)							
Rainwater tank	1401	1544	1657	Same as ‘Basic Scenario’			
Pump	722	790	962				
Plumbing	759	900	1017				
Tank installation	334	350	400				
Laying concrete slab	597	700	803				
Pump installation	200	250	300				
Operating, Maintenance and Replacement							
Energy							
Specific energy (kWh/kL)	1.1	1.48	1.9	Same as ‘Basic Scenario’			
Unit cost for energy in 2012 ($/kWh)		0.2276					
Retail energy price path real growth rate (%)	3	5	7				
Useful lives (years)							
Pump life	5	10	15				
Rainwater tank life	15	25	35				
Plumbing		50					
Maintenance ($AUD2012)	0	20	54	54	104	184	Same as ‘Alternative Scenario’
Yield (kL/year)							
Brisbane	18	42	76	Same as ‘Basic Scenario’			Fitted distribution
Moreton Bay	16	43	78				
Sunshine Coast	24	48	90				
Ipswich	10	34	66				
Gold Coast	18	44	74				

4. RESULTS

The following results present the levelised cost for the ‘basic scenario’ of a 50-year period of analysis, 3% discount rate and maintenance based on current practice as outlined in Table 10. Table 11 provides a comparison of the levelised cost for rainwater tanks in various locations in SEQ as well as an average for SEQ.

The results were described in terms of the mean to reflect the performance of the whole population including the effect of the skew in the distribution. The mode and median were also used to show the most frequent value as well as the 50th percentile. The shape of the distributions can be seen in the ‘skewness’ measure, difference in the mean and mode and the 97.5th percentile. The addition of the distributions to form the SEQ weighted average reduced the skew and increased the mode towards the mean.

The Sunshine Coast was the most cost-effective location for a rainwater tank with a mean levelised cost of $7.62/kL. Ipswich was the least cost-effective location for a rainwater tank with a mean levelised cost of $11.17/kL. The distribution for Ipswich also had the highest skew and produced a relatively high upper 95% confidence limit of $22.19/kL.

Table 11. Summary of 'Basic Scenario' Levelised Cost for Rainwater Tanks in SEQ.

Name	Mean	Mode	Median	Std Dev	Skewness	2.5%	97.5%
Brisbane Rainwater Tank Levelised Cost	8.93	7.18	8.42	2.46	1.12	5.59	15.10
Moreton Bay Rainwater Tank Levelised Cost	8.97	7.12	8.38	2.70	1.32	5.49	16.10
Sunshine Coast Rainwater Tank Levelised Cost	7.62	6.19	7.28	1.91	0.95	4.90	12.23
Ipswich Rainwater Tank Levelised Cost	11.17	8.15	10.17	4.05	1.64	6.40	22.19
Gold Coast Rainwater Tank Levelised Cost	8.90	7.99	8.41	2.40	1.20	5.65	15.08
SEQ Weighted Average	9.22	9.04	9.03	1.57	0.78	6.73	12.77

Figure 2 illustrates the probability density chart for Brisbane and Figure 3 presents a ‘tornado’ chart for Brisbane rainwater tank cost-effectiveness. The Appendices provide similar charts for the other local government areas. Figure 4 presents an average levelised cost for SEQ based upon weighting outlined in Table 2. The ‘tornado’ chart illustrates the effect on the levelised cost from a one standard deviation change in the input variable. A one standard deviation change in the yield produced a large change in the levelised cost. Analysis of variables affecting yield was based on Maheepala *et al.* 2013 and was summarised in the following results. Important cost variables were the pump life, rainwater tank life, maintenance, growth in electricity prices and pump cost. Note that cost variables are currently considered as independent variables and this assumption may require review. For example, a high initial capital cost for a pump may be associated with a longer life and lower energy costs.

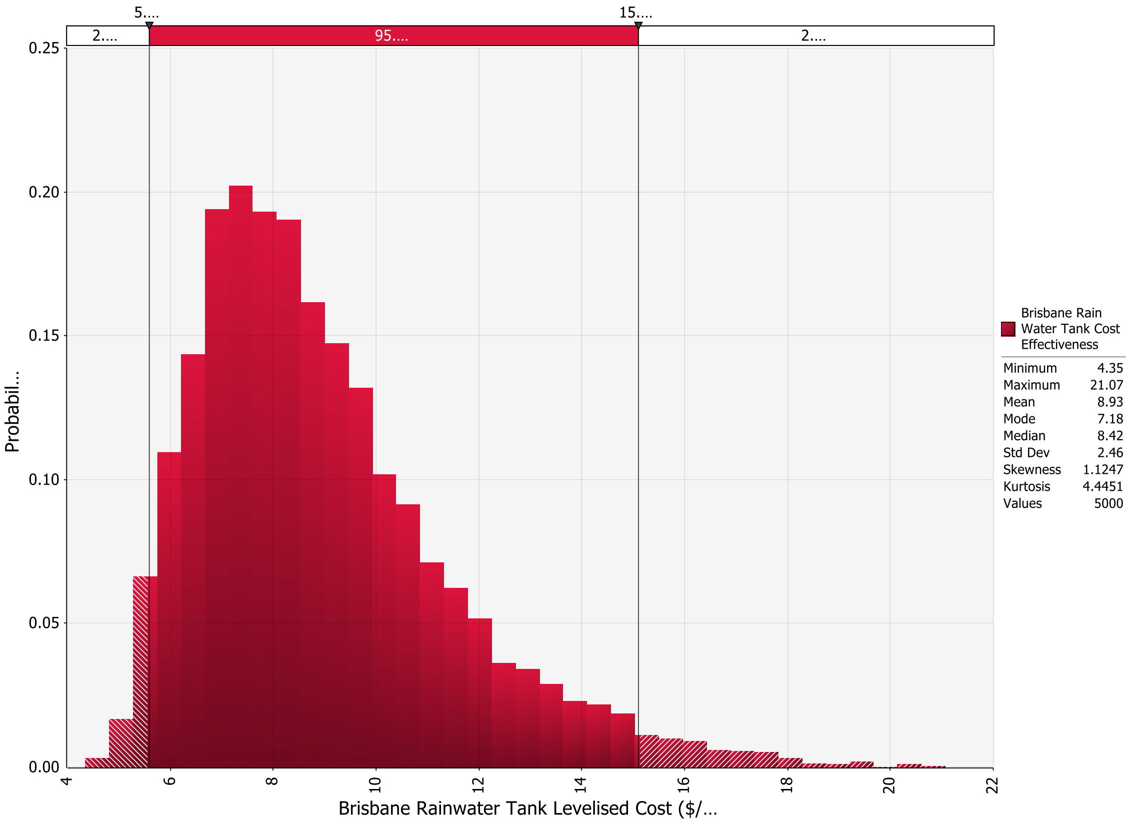


Figure 2. Brisbane Rainwater Tank Cost-effectiveness Probability Density

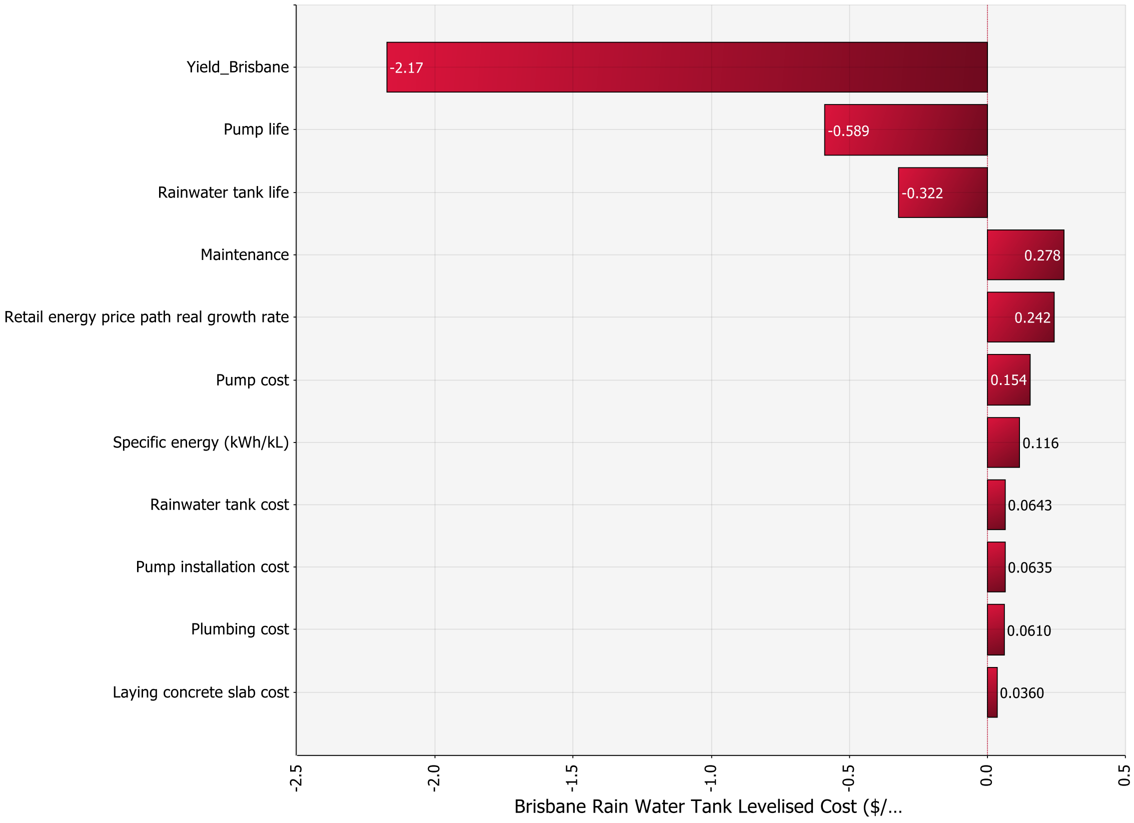


Figure 3. Brisbane Rainwater Tank Cost-effectiveness Tornado Chart.

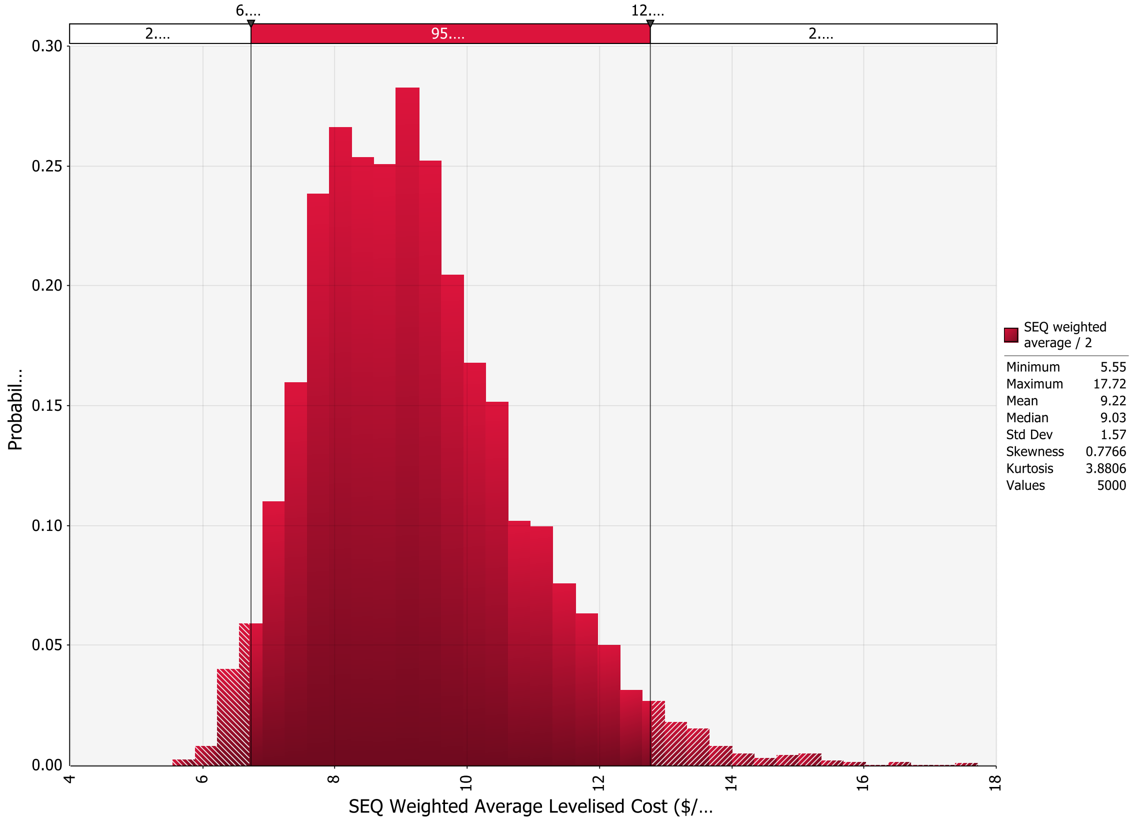


Figure 4. **SEQ Weighted Average Rainwater Tank Cost-effectiveness Probability Density.**

4.1. Variables Affecting the Yield

Table 11 provides a summary of the variables affecting the yield calculations based upon Maheepala *et al.* 2013. The data illustrates that the yield calculated on the average of each variable was 50.13 kL/yr and was greater than when a distribution of values was used to calculate the average yield of 43.37 kL/yr. This suggests that an estimate that does not consider variability results in an over-estimate of the yield by about 16%. The average yield was then calculated by varying each parameter and using the average for the other parameters. The results suggest that each variable (and especially tank size and roof area) has a relatively large effect on the yield when considered in isolation (ie, when the other parameters do not vary). However, this effect was moderated when all the variables were considered at the same time. For example, a greater roof area might produce more water but if demand is low then the water won't be used and there will also be more overflows.

Table 11. **Variables affecting the yield (Based on Maheepala *et al.* 2013).**

	Parameter Varied	Average Yield per Year (kL/yr)	Average Overflow per Year (kL/yr)	Yield Percentage Difference Compared to Fully Variable Case (%)	Overflow Percentage Difference Compared to Fully Variable Case (%)
	Demand	46.13	58.87	6%	-5%
	Tank	49.26	55.77	14%	-10%
	Roof	48.15	54.9	11%	-8%
Fully Average Case		50.13	54.9	16%	-11%
Fully Variable Case		43.37	61.78		

5. SENSITITY ANALYSIS

The sensitivity analysis explored changes in the discount rate, the period of analysis, assumptions for maintenance and the fitting of distributions for yield. Only one variable was changed at time with the other variables set to the 'basic' scenario. The sensitivity analysis presents the results for the SEQ weighted average for most variables. The fitting of distributions for the yield considered the Brisbane LGA because yield distributions were only available at the LGA scale.

5.1. Discount Rate

The discount rate was increased from 3% to 6% and 9% and resulted in the mean levelised cost for SEQ increasing from $9.22/kL to $11.41/kL and $14.01/kL respectively. Figure 5 and Figure 6 illustrate the distribution of cost-effectiveness for SEQ rainwater tanks with a 6 and 9% discount rate. The large change in the discount rate affected both the operating costs and the yield which reduced the effect on the levelised cost.

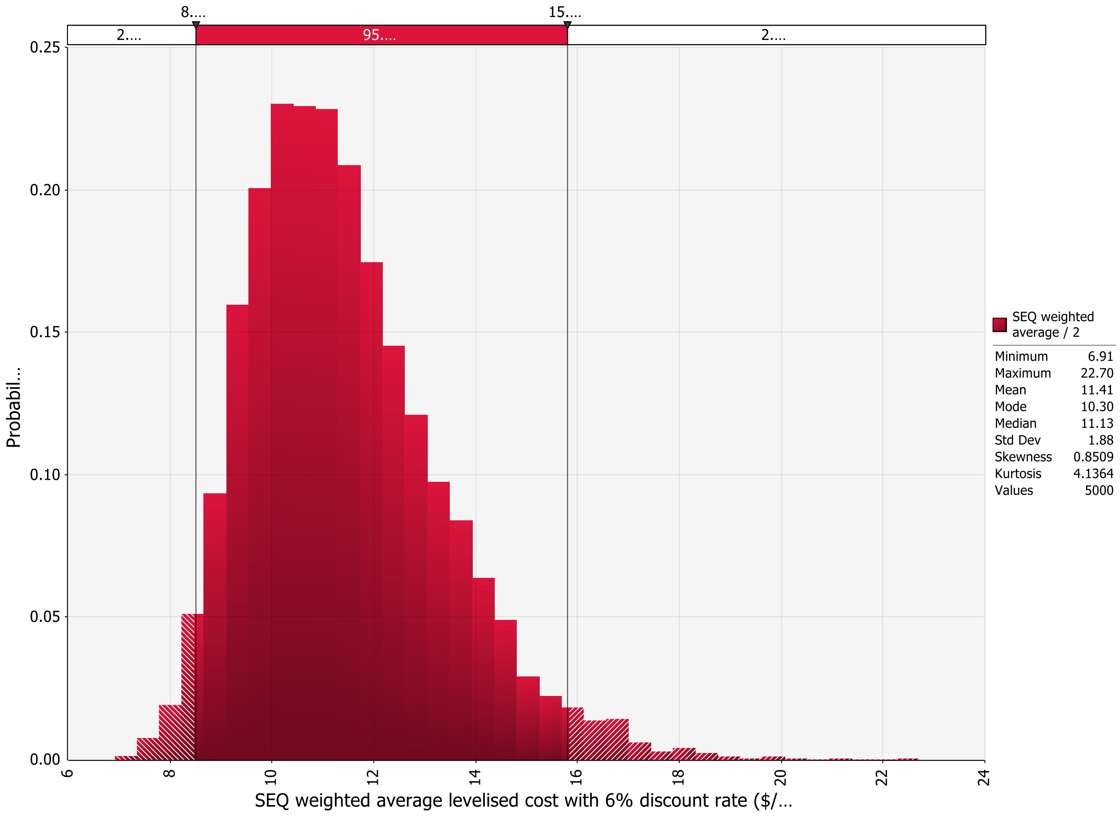


Figure 5. SEQ Average Rainwater Tank Levelised Cost with a 6% Discount Rate.

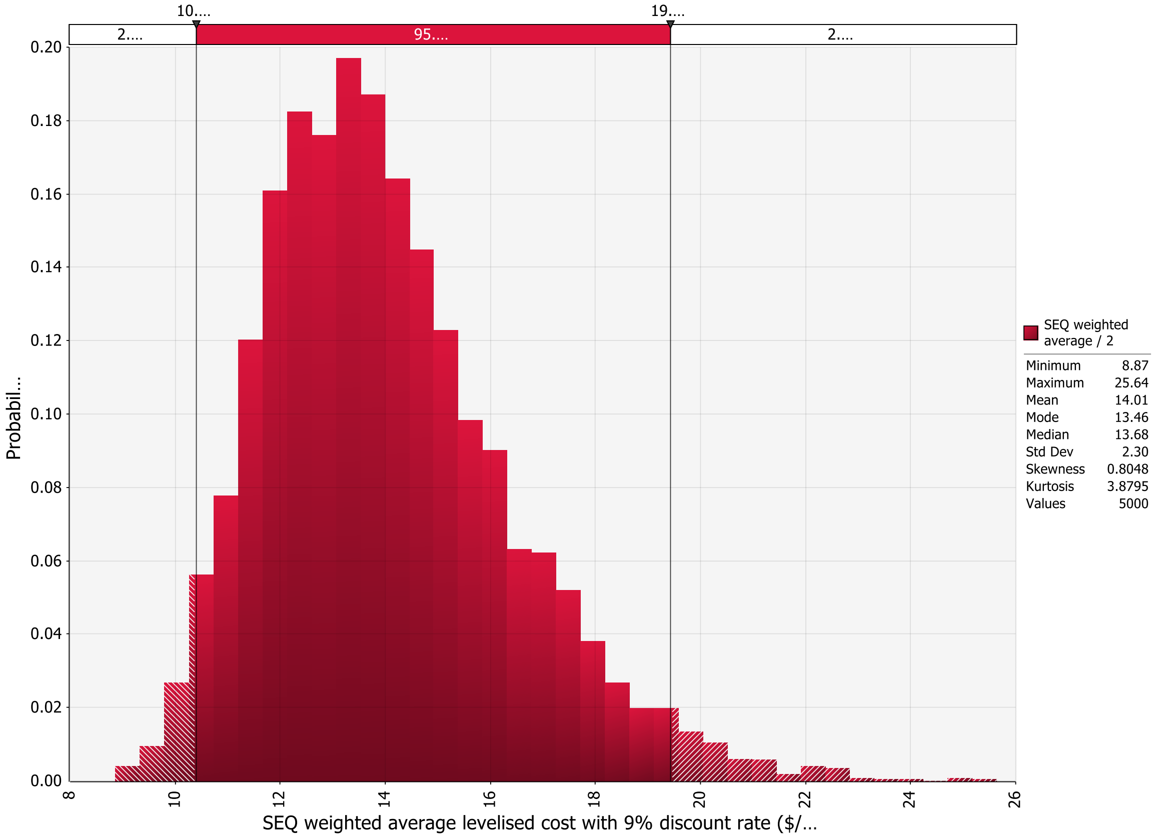


Figure 6. **SEQ Average Rainwater Tank Levelised Cost with a 9% Discount Rate.**

5.2. Period of Analysis

The period of analysis was halved from 50 to 25 years and resulted in a small increase in the average levelised cost for SEQ from $9.22/kL to $9.54/kL. The halving of the period of analysis reduced the effect of discounting of operating costs and yields compared to capital costs. Figure 7 illustrates the change in the distribution for a halving of the period of analysis.

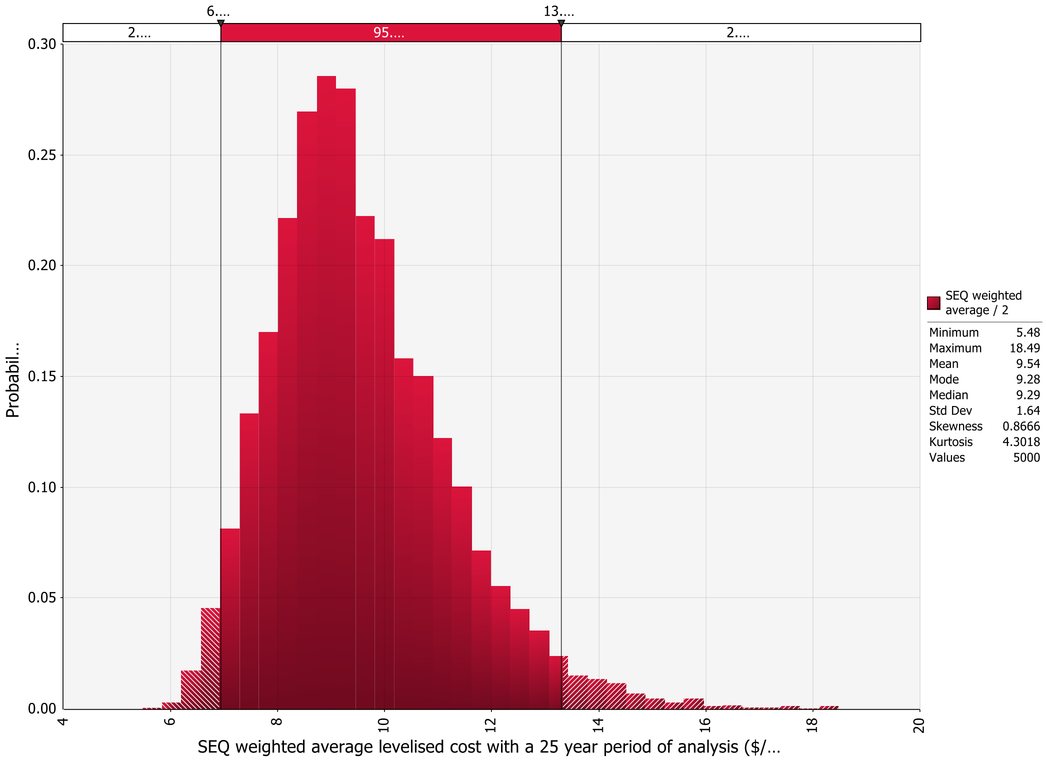


Figure 7. **SEQ Average Rainwater Tank Levelised Cost with a 25-Year Period of Analysis.**

5.3. Maintenance

The maintenance costs were changed from current practice to recommended practice as outlined in Table 10. The change in maintenance practice increased the mean levelised cost for SEQ rain water tanks from $9.22 to $11.49/kL. Figure 8 illustrates the probability distribution for the 'basic scenario' with recommended maintenance.

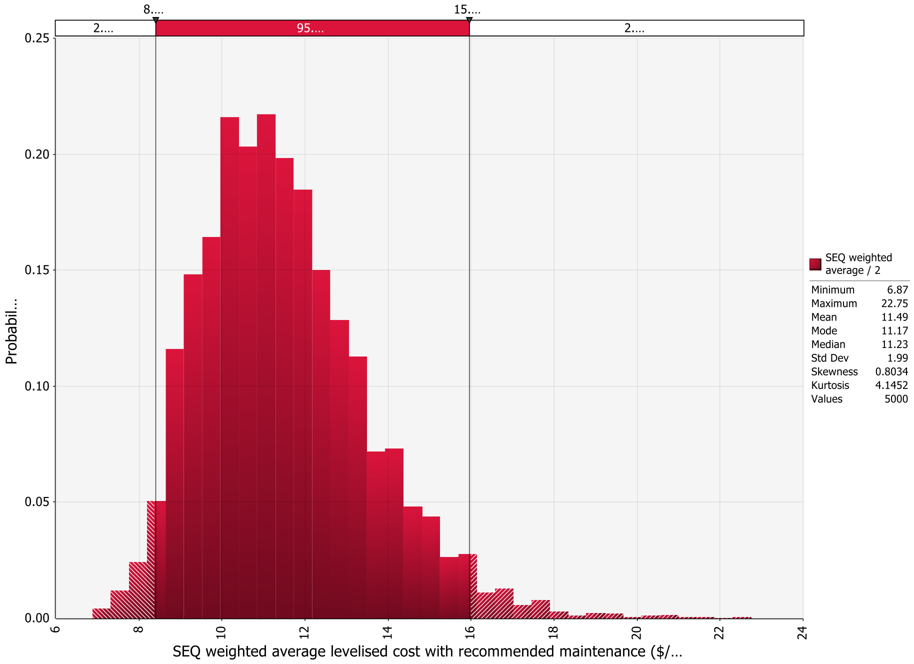


Figure 8. **SEQ Average Rainwater Tank Levelised Cost with Maintenance Based Upon Recommended Practice.**

5.4. Fitting Distributions for the Yield

The assumed triangular distribution was replaced by a fitted distribution to consider the effect upon the cost-effectiveness. Figure 9 illustrates the fit of the JohnsonSU distribution to the Brisbane rainwater tank yield. The JohnsonSU distribution was the highest ranked distribution and Appendix 1 provides details of the distributions considered and their goodness of fit. Table 12 presents a comparison of Brisbane rainwater tank cost-effectiveness with a triangular and fitted distribution for the yield. The main difference was the cost-effectiveness with a fitted distribution had a higher upper 95% confidence limit. This reflects the truncation of the tails using the triangular distribution. The mean and median were very similar for both distributions.

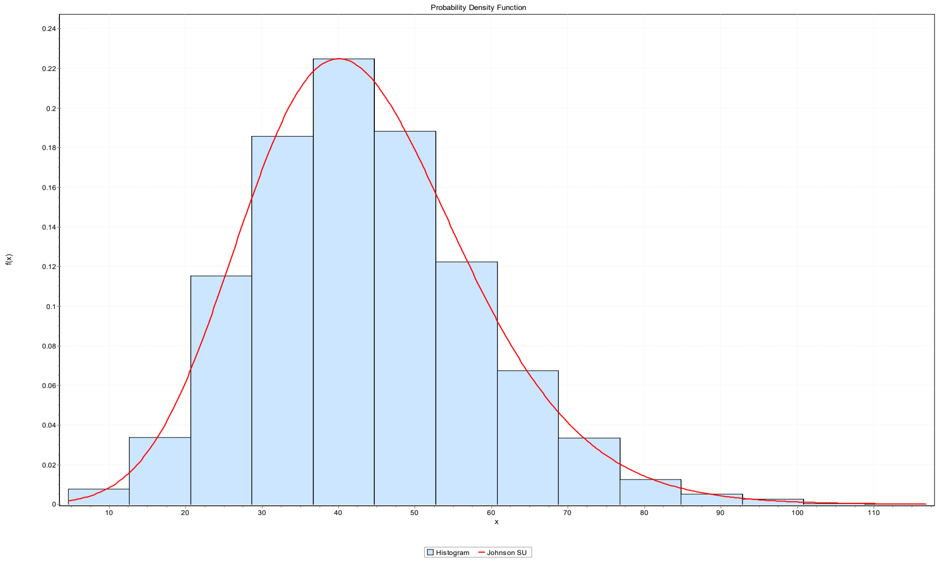


Figure 9. **Fit of the JohnsonSU distribution to the Brisbane rainwater tank yield.**

Table 12. **Sensitivity of Brisbane Rainwater Tank Cost-effectiveness to the Yield Distribution.**

	Cost-Effectiveness ($/kL)			
	Median	**Mean**	**Lower 95% Confidence Interval**	**Upper 95% Confidence Interval**
Yield with triangular distribution	3.38	3.59	2.19	6.19
Yield with JohnsonSU distribution	3.57	3.82	2.0	8.46

5.5. Alternative Scenario

The 'Alternative' scenario assumes a 25-year period of analysis, a 6% discount rate and maintenance costs following recommended practice (Figure 10). This scenario provides a higher time cost of money comparable to the current WACC for water and wastewater utilities as well as periods of analysis common for other infrastructure appraisals (for example (NSWTreasury 1999), (BlighTanner 2009) (CH2MHILL 2008). The maintenance cost follows recommended practice and addresses potential health risks not captured in the levelised cost metric. The change from the 'Basic Scenario' to the 'Alternate Scenario' increases the mean levelised cost from $9.22/kL to $14.11/kL

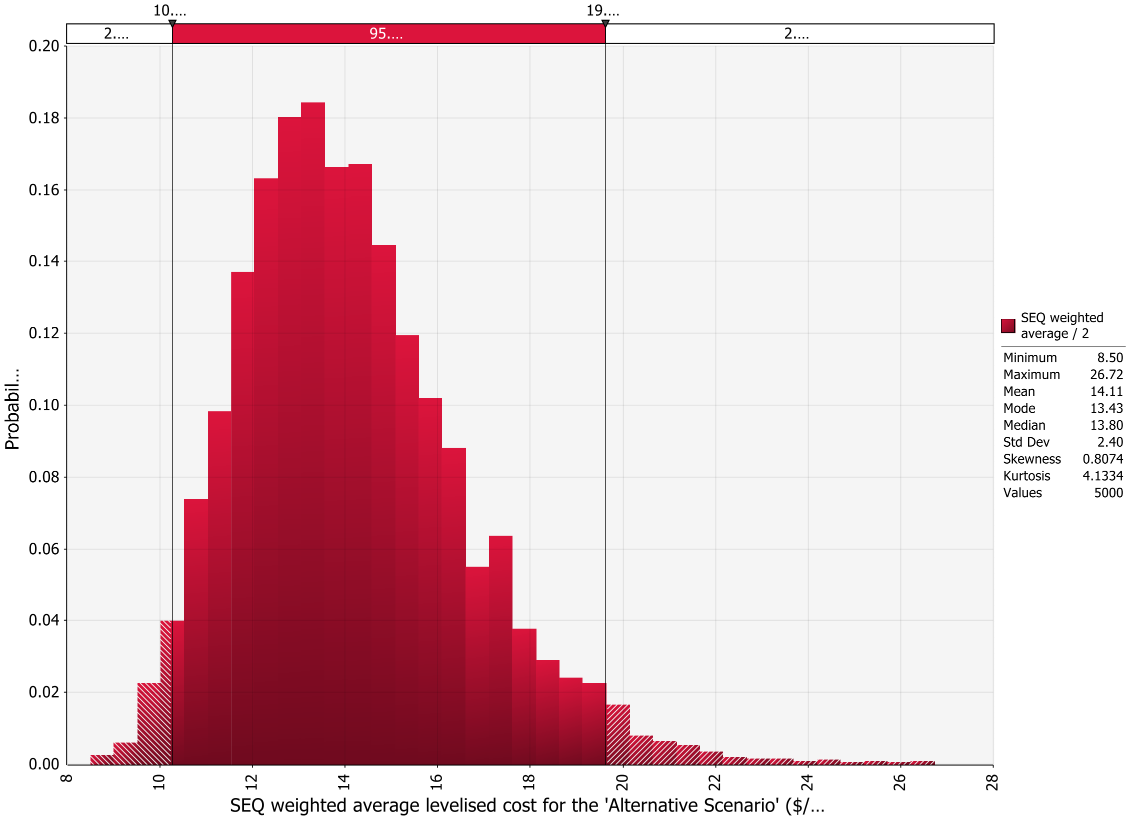


Figure 10. Alternative scenario for SEQ Weighted Average for Rainwater Tank Cost-effectiveness.

6. CONCLUSIONS

The results of the analysis were not directly comparable to the results in Marsden Jacobs Associates (2007) *The cost-effectiveness of rainwater tanks in urban Australia* (MJA 2007). The MJA 2007 report considered the avoided cost to the household for purchasing water from the centralised water supply. This approach does not allow comparison of the cost-effectiveness of rainwater tanks with centralised supplies because the later is also included in the calculation of the former. In addition, there has been significant change in demand and end-use patterns in SEQ over the past six years. The MJA 2007 estimate of cost-effectiveness for a 5 kL rainwater tank in Brisbane was $2.29 and $5.47/kL for a 200 and 50 square metre connected roof areas respectively.

Financial assumptions and assumed maintenance practice had a large effect upon the cost-effectiveness estimates as demonstrated by the two scenarios which drew upon the same yield data. The 'Basic Scenario' had a 50-year period of analysis, a 3% discount rate based on government bond rates and maintenance based upon current practice. The rainwater tank cost-effectiveness in SEQ for this scenario was an average levelised cost of $9.22/kL with lower and upper limits of a 95% confidence of $6.73 and $12.77/kL. In comparison, the 'Alternative Scenario' had a 6% discount rate, a time frame for infrastructure appraisal of 25 years as well as maintenance according to recommended practice. The SEQ average levelised cost for this scenario was $14.11/kL with lower and upper 95% confidence limits of $10.27 and $19.62/kL.

The variation in rainfall across the SEQ region also had an effect on the cost-effectiveness of rainwater tanks. The Sunshine Coast was the most cost-effective location for a rainwater tank with an average levelised cost of $7.62/kL. Ipswich was the least cost-effective location for a rainwater tank with an average levelised cost of $11.17/kL. The distribution for Ipswich also had the highest skew and had a relatively high upper 95% confidence limit of $22.19/kL. Other LGAs considered fell within this range with Brisbane, Moreton Bay and the Gold Coast average levelised costs of $8.93, $8.97 and $8.90/kL respectively.

Rainwater tank yield within a LGA was affected by the roof area, tank size and demand profile. Considering the variability in each parameter resulted in a yield which was 16% lower than a yield calculated on average values. The consideration of input distributions captured cases such as a large roof area and tank size coupled with low demand which resulted in lower yields and greater tank overflow.

The variation in the results within an area which has the same rainfall suggests the potential to improve the performance of rainwater tanks. This is particularly true for the least cost-effective tanks within a region, which showed a large difference between the worst performance and the most likely performance in the region. Guidance for maintenance of rainwater tanks is also required to shift from current practice to recommended health guidelines.

In addition, the relatively poor performance of the least cost-effective rainwater tanks may have been underestimated in this study by using a triangular distribution which truncated the upper and lower range of the tail. Additional sampling is required to determine the likelihood of very large values, which are currently considered as outliers, and to develop a more appropriate distribution. This in turn may suggest the need for quality control on the set-up of rainwater tanks to ensure expected performance in a location.

Finally, some variables may not be independent and the current calculation of cost-effectiveness may require further analysis. For example, a high initial capital cost for a pump may be associated with a longer life and lower energy costs. This requires further data collection of cost and performance data which may also be useful to inform consumer choice.

APPENDIX 1: Probability Distributions for the ‘Basic Scenario’ for each SEQ LGA Considered

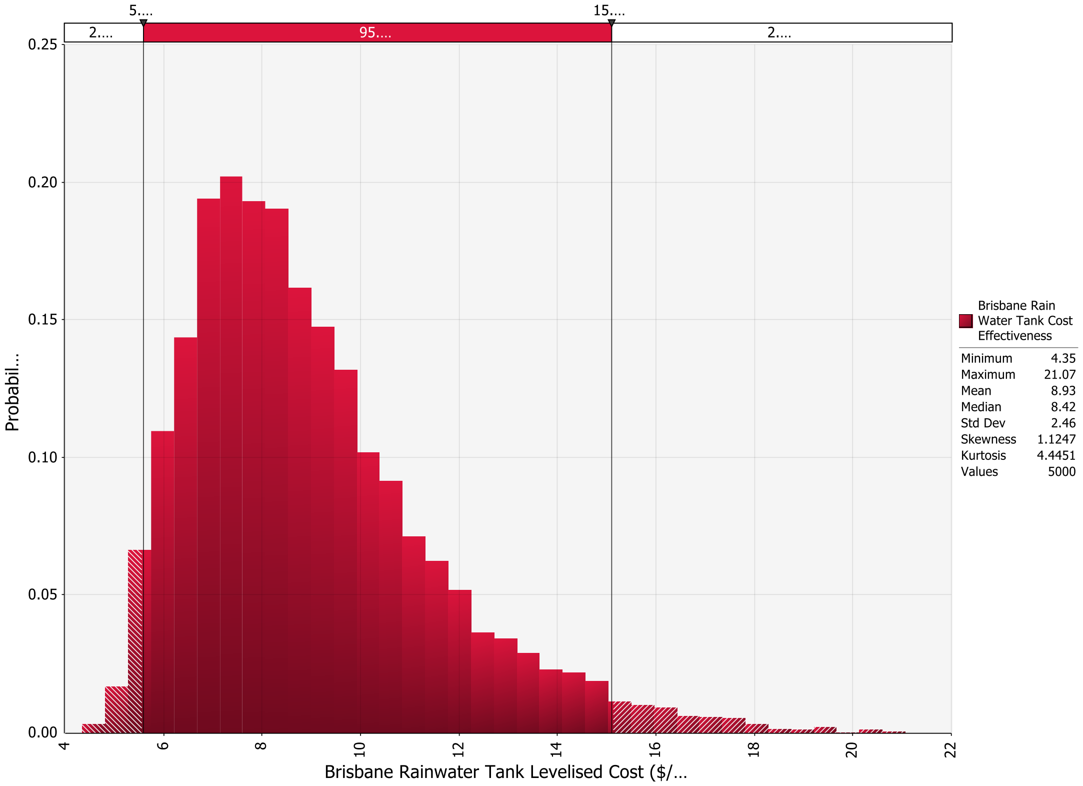


Figure 11. **Brisbane Rainwater Tank Levelised Cost Probability Density.**

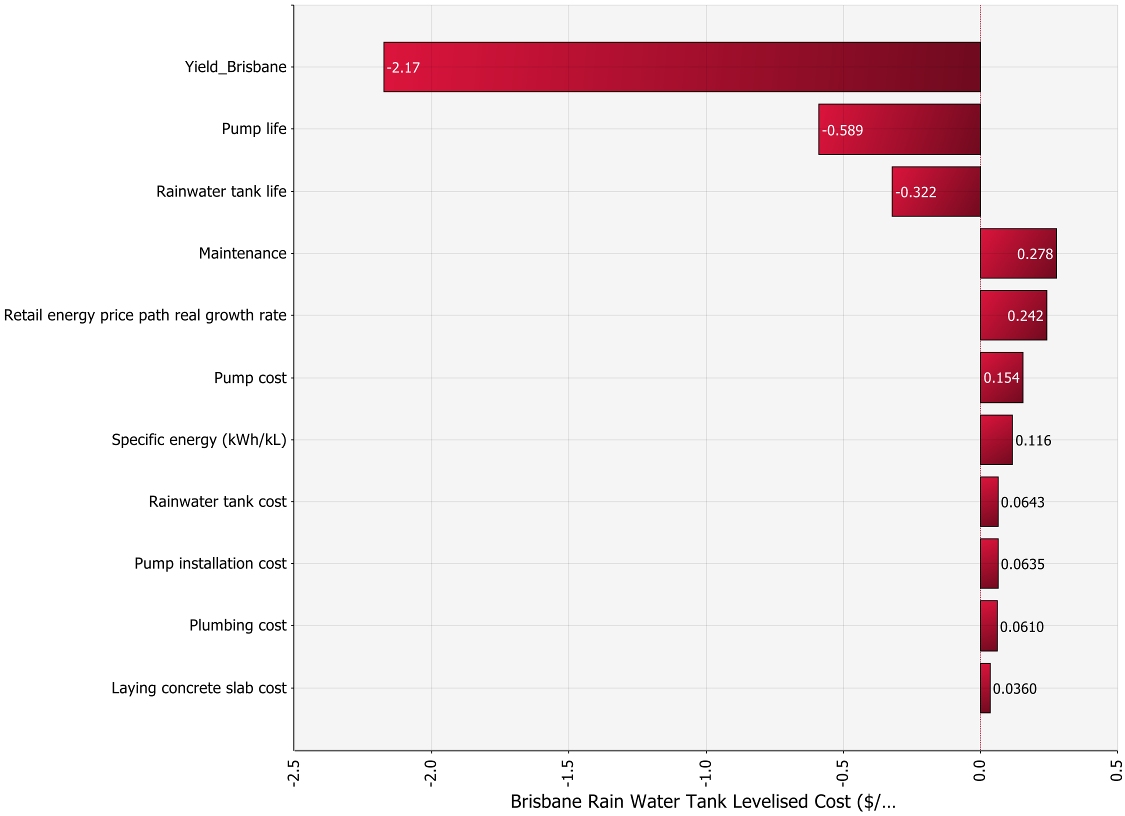


Figure 12. **Brisbane Rainwater Tank Levelised Cost Tornado Chart.**

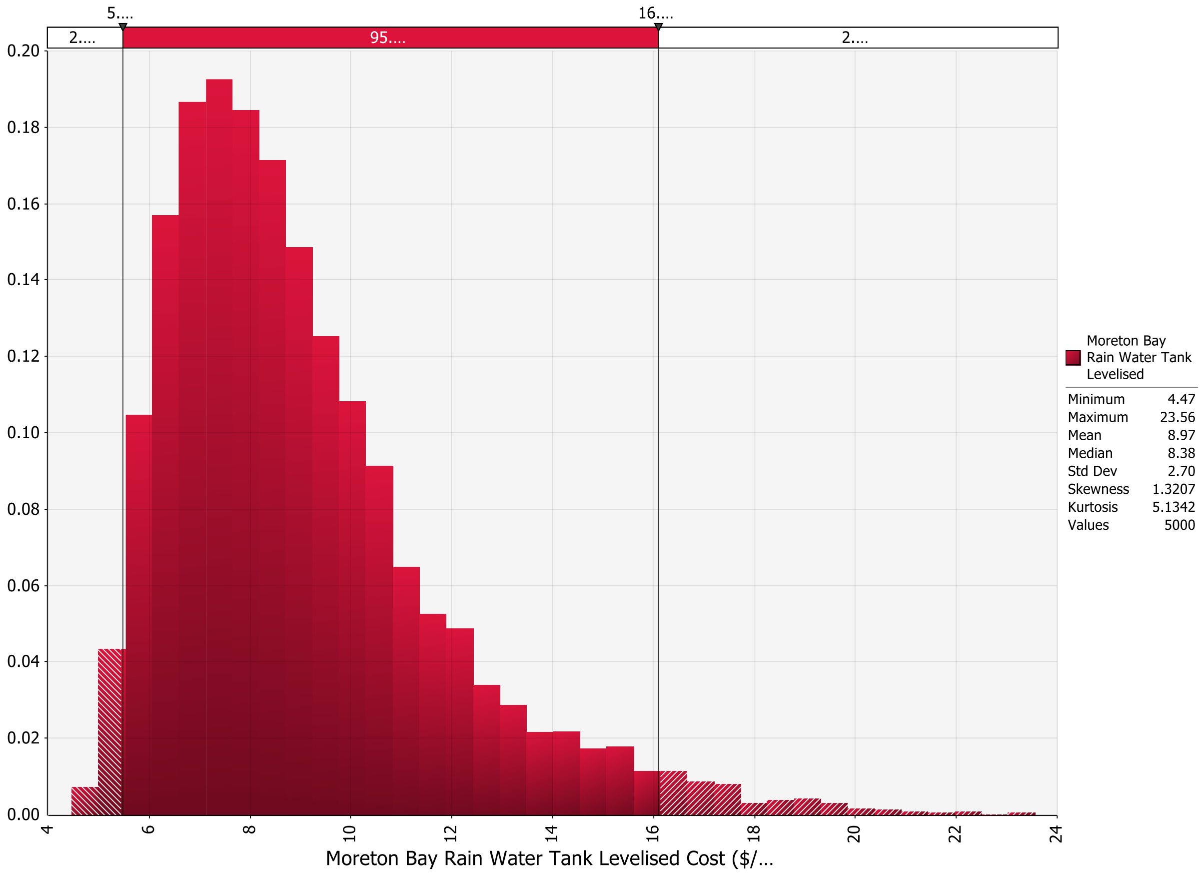


Figure 13. **Moreton Bay Rainwater Tank Levelised Cost Probability Density.**

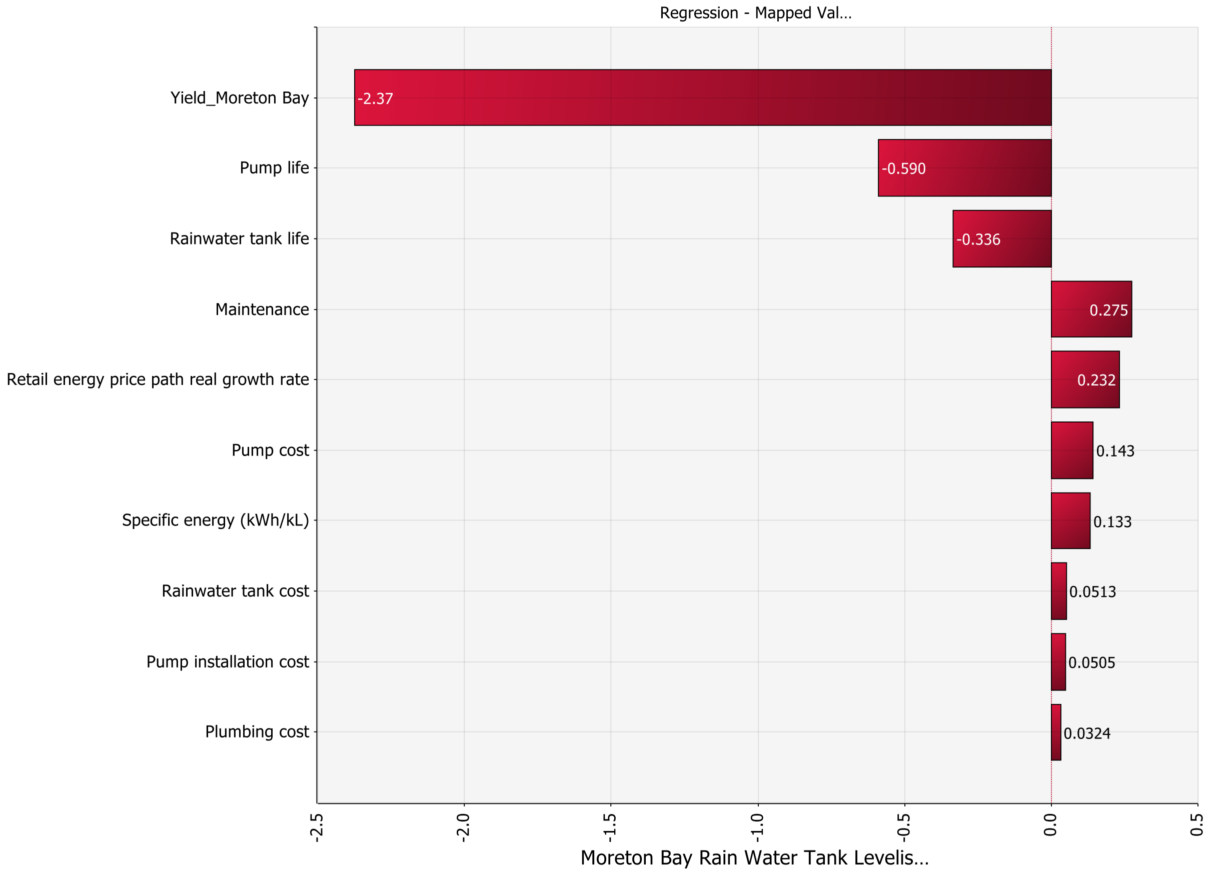


Figure 14. **Moreton Bay Rainwater Tank Levelised Cost Tornado Chart.**

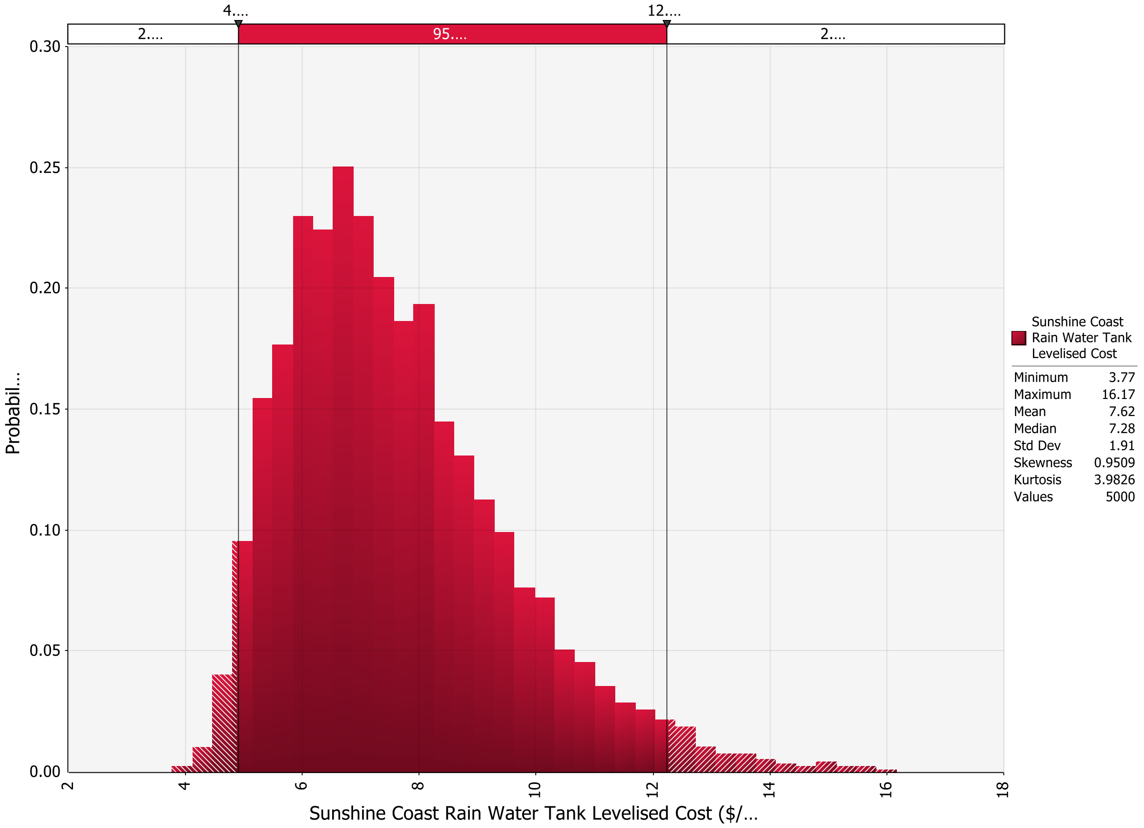


Figure 15. Sunshine Coast Rainwater Tank Levelised Cost Probability Density.

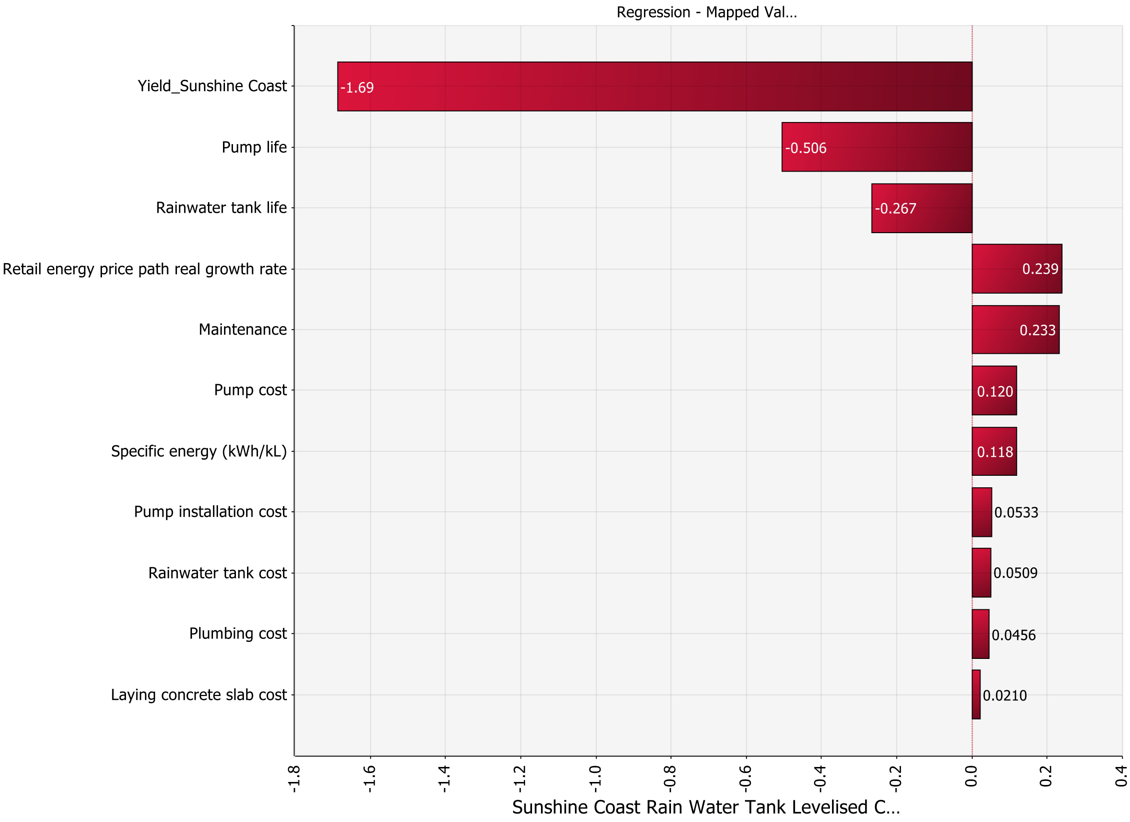


Figure 16. Sunshine Coast Rainwater Tank Levelised Cost Tornado Chart.

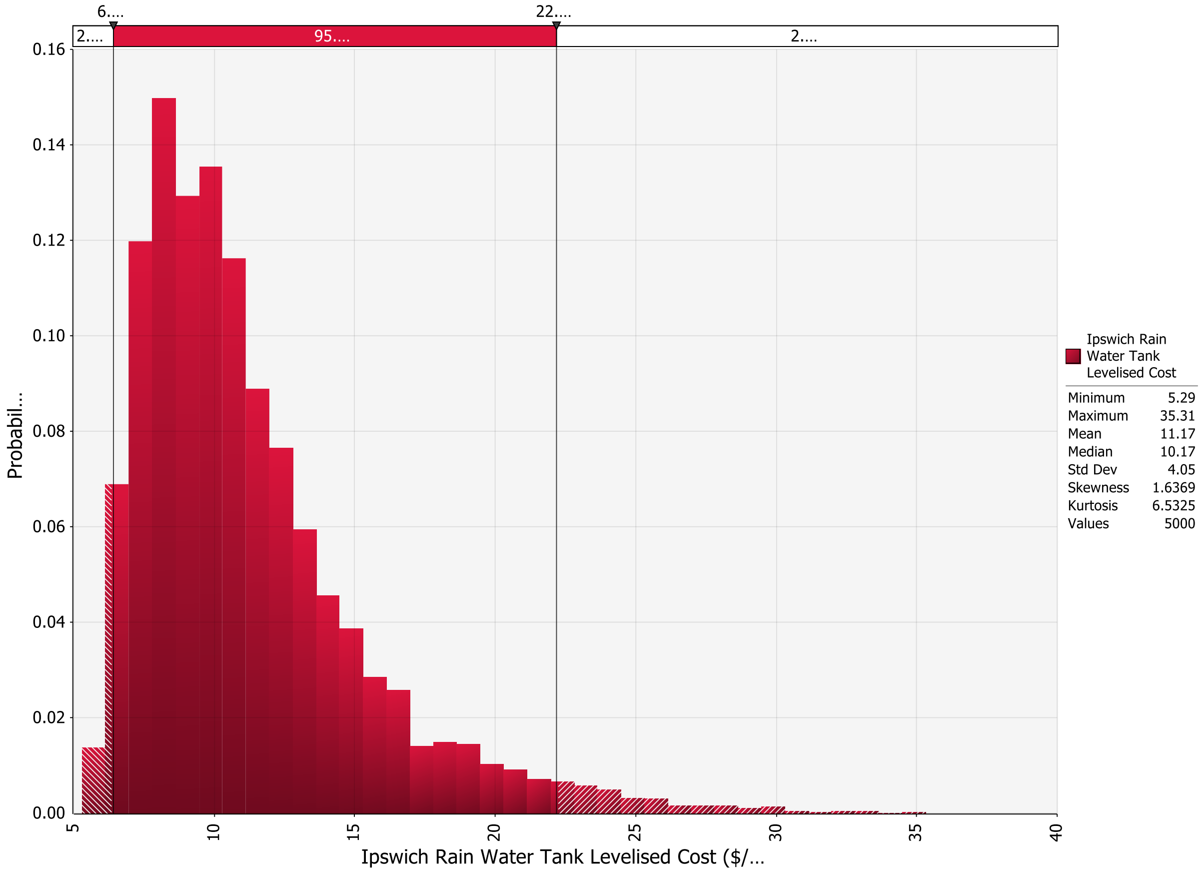


Figure 17. Ipswich Rainwater Tank Levelised Cost Probability Density.

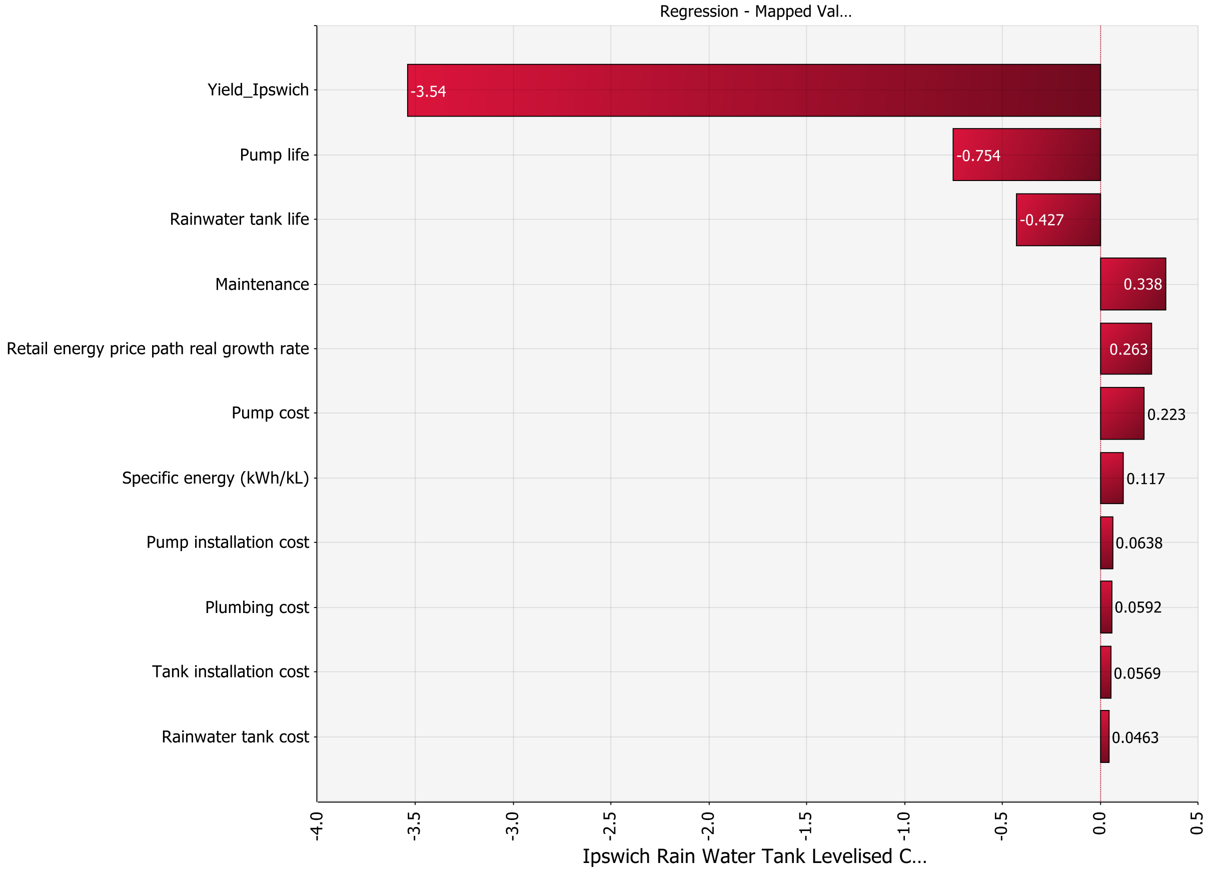


Figure 18. Ipswich Rainwater Tank Levelised Cost Tornado Chart.

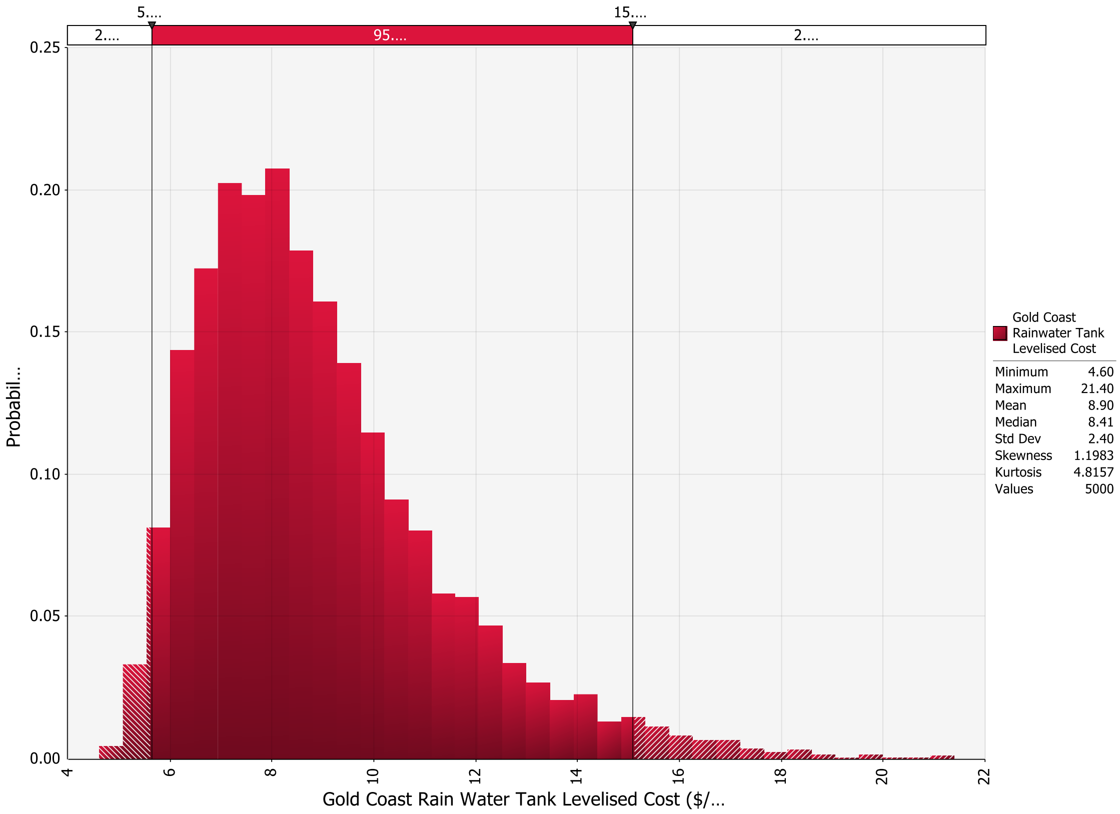


Figure 19. **Gold Coast Rainwater Tank Levelised Cost Probability Density.**

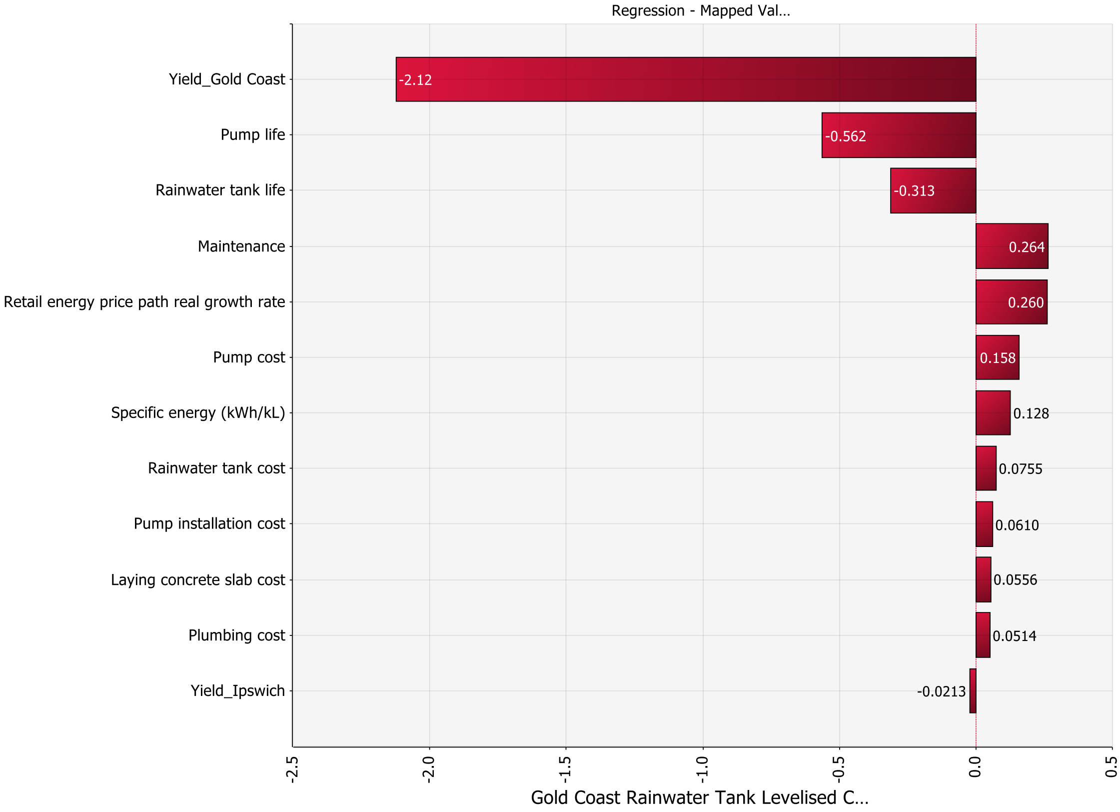


Figure 20. **Gold Coast Rainwater Tank Levelised Cost Tornado Chart.**

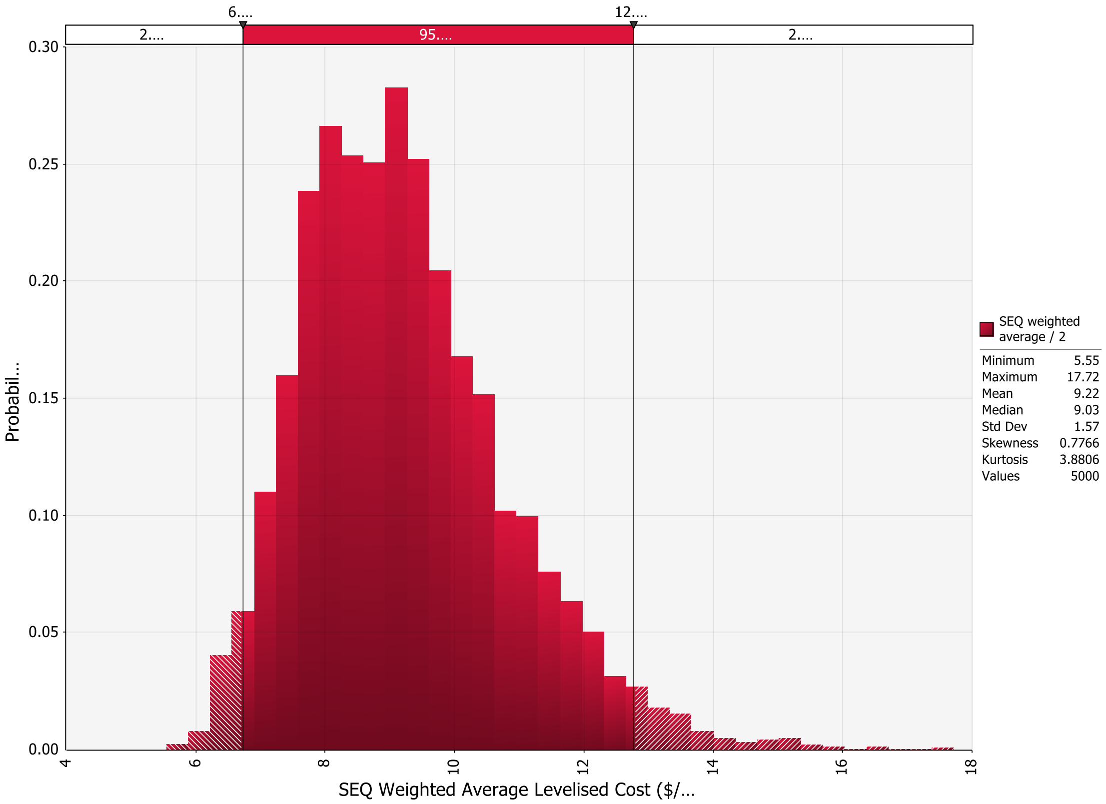


Figure 21. **SEQ Weighted Average Rainwater Tank Levelised Cost Probability Density.**

APPENDIX 2: SEQ Rainwater Tank Yield: Fitting Probability Distribution Functions

By Shiroma Maheepala and Esther Coultas

All tank yield data are sourced from Maheepala *et al.* (2013). The analysis is carried out for five LGAs: Brisbane, Moreton bay, Sunshine Coast, Gold Coast and Ipswich.

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Descriptive Statistics

Statistic	Value	Percentile	Value
Sample Size	10000	Min	4.6393
Range	112.19	5%	21.298
Mean	43.369	10%	25.314
Variance	217.18	25% (Q1)	33.017
Std. Deviation	14.737	50% (Median)	42.264
Coef. of Variation	0.3398	75% (Q3)	52.456
Std. Error	0.14737	90%	62.731
Skewness	0.47898	95%	69.698
Excess Kurtosis	0.45299	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

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
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
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

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
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 – Details

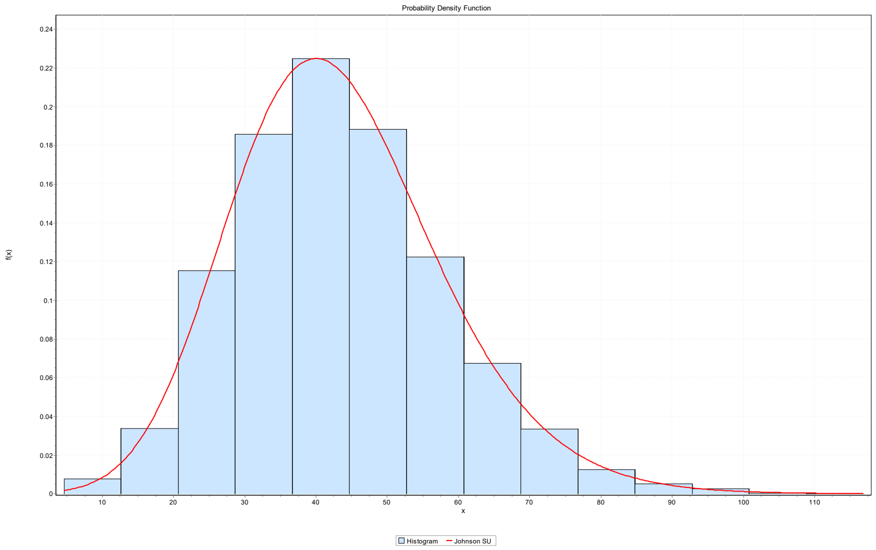
Johnson SU [#31]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	10000 0.00606 0.85365 1				
□	0.2	0.1	0.05	0.02	0.01
Critical Value	0.01073	0.01223	0.01358	0.01518	0.01629
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	10000 0.44284 1				
□	0.2	0.1	0.05	0.02	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				
□	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

Fitting Results

#	Distribution	Parameters
1	Beta	$\alpha_1=18.123$ $\alpha_2=392.67$ $a=-20.738$ $b=1434.3$
2	Burr	$k=3.2231$ $\alpha=3.8065$ $\beta=61.697$
3	Burr (4P)	$k=2.8947$ $\alpha=4.0312$ $\beta=60.942$ $\gamma=-1.6453$
4	Cauchy	$\sigma=8.7097$ $\mu=41.842$
5	Chi-Squared	$\nu=43$
6	Chi-Squared (2P)	$\nu=104$ $\gamma=-61.559$
7	Dagum	$k=0.50248$ $\alpha=6.7166$ $\beta=50.013$
8	Dagum (4P)	$k=289.18$ $\alpha=13.534$ $\beta=80.86$ $\gamma=-114.77$
9	Erlang	$m=8$ $\beta=5.0076$
10	Erlang (3P)	$m=21$ $\beta=3.2073$ $\gamma=-24.114$
11	Error	$k=1.6552$ $\sigma=14.737$ $\mu=43.369$
12	Error Function	$h=0.04798$
13	Exponential	$\lambda=0.02306$
14	Exponential (2P)	$\lambda=0.02582$ $\gamma=4.6393$
15	Fatigue Life	$\alpha=0.38628$ $\beta=40.342$
16	Fatigue Life (3P)	$\alpha=0.15054$ $\beta=96.425$ $\gamma=-54.148$
17	Frechet	$\alpha=3.1365$ $\beta=33.865$
18	Frechet (3P)	$\alpha=1.4283$ $\beta=28.003$ $\gamma=4.5323$
19	Gamma	$\alpha=8.6606$ $\beta=5.0076$
20	Gamma (3P)	$\alpha=21.041$ $\beta=3.2073$ $\gamma=-24.114$
21	Gen. Extreme Value	$k=-0.15049$ $\sigma=13.411$ $\mu=37.388$
22	Gen. Gamma	$k=0.98494$ $\alpha=8.3712$ $\beta=5.0076$
23	Gen. Gamma (4P)	$k=1.3447$ $\alpha=8.4928$ $\beta=11.877$ $\gamma=-14.316$
24	Gen. Logistic	$k=0.07678$ $\sigma=8.1551$ $\mu=42.332$
25	Gen. Pareto	$k=-0.71478$ $\sigma=38.335$ $\mu=21.014$
26	Gumbel Max	$\sigma=11.49$ $\mu=36.737$
27	Gumbel Min	$\sigma=11.49$ $\mu=50.002$
28	Hypersecant	$\sigma=14.737$ $\mu=43.369$
29	Inv. Gaussian	$\lambda=375.6$ $\mu=43.369$
30	Inv. Gaussian (3P)	$\lambda=4320.1$ $\mu=97.824$ $\gamma=-54.455$
31	Johnson SU	$\gamma=-6.6105$ $\delta=5.3974$ $\lambda=42.038$ $\xi=-23.12$
32	Kumaraswamy	$\alpha_1=2.8752$ $\alpha_2=473.02$ $a=3.389$ $b=385.21$
33	Laplace	$\lambda=0.09596$ $\mu=43.369$
34	Levy	$\sigma=37.557$

#	Distribution	Parameters
35	Levy (2P)	$\sigma=31.253$ $\gamma=3.9216$
36	Log-Gamma	$\alpha=98.469$ $\beta=0.03764$
37	Log-Logistic	$\alpha=4.7689$ $\beta=40.703$
38	Log-Logistic (3P)	$\alpha=10.291$ $\beta=84.947$ $\gamma=-42.758$
39	Log-Pearson 3	$\alpha=4.6833$ $\beta=-0.17259$ $\gamma=4.5147$
40	Logistic	$\sigma=8.1249$ $\mu=43.369$
41	Lognormal	$\sigma=0.37349$ $\mu=3.7064$
42	Lognormal (3P)	$\sigma=0.15132$ $\mu=4.5607$ $\gamma=-53.383$
43	Nakagami	$m=2.184$ $\Omega=2098.1$
44	Normal	$\sigma=14.737$ $\mu=43.369$
45	Pareto	$\alpha=0.46044$ $\beta=4.6393$
46	Pareto 2	$\alpha=161.21$ $\beta=5175.7$
47	Pearson 5	$\alpha=6.3689$ $\beta=239.19$
48	Pearson 5 (3P)	$\alpha=3.1135$ $\beta=93.945$ $\gamma=4.5106$
49	Pearson 6	$\alpha_1=10.103$ $\alpha_2=41.765$ $\beta=171.5$
50	Pearson 6 (4P)	$\alpha_1=530.84$ $\alpha_2=54.94$ $\beta=10.655$ $\gamma=-61.91$
51	Pert	$m=36.714$ $a=4.5674$ $b=116.92$
52	Phased Bi-Exponential	$\lambda_1=0.01301$ $\gamma_1=4$ $\lambda_2=0.19057$ $\gamma_2=38.859$
53	Phased Bi-Weibull	$\alpha_1=1.0545$ $\beta_1=1313.5$ $\gamma_1=4$ $\alpha_2=2.9217$ $\beta_2=48.541$ $\gamma_2=7.5378$
54	Power Function	$\alpha=0.86291$ $a=4.6294$ $b=116.83$
55	Rayleigh	$\sigma=34.604$
56	Rayleigh (2P)	$\sigma=29.322$ $\gamma=4.6086$
57	Reciprocal	$a=4.6393$ $b=116.83$
58	Rice	$\nu=40.257$ $\sigma=15.451$
59	Student's t	$\nu=2$
60	Triangular	$m=33.357$ $a=4.4601$ $b=116.85$
61	Uniform	$a=17.844$ $b=68.894$
62	Wakeby	$\alpha=112.78$ $\beta=6.9932$ $\gamma=18.427$ $\delta=-0.23622$ $\xi=14.353$
63	Weibull	$\alpha=3.4139$ $\beta=48.196$
64	Weibull (3P)	$\alpha=2.8894$ $\beta=44.83$ $\gamma=3.3496$
65	Johnson SB	No fit

Johnson SU



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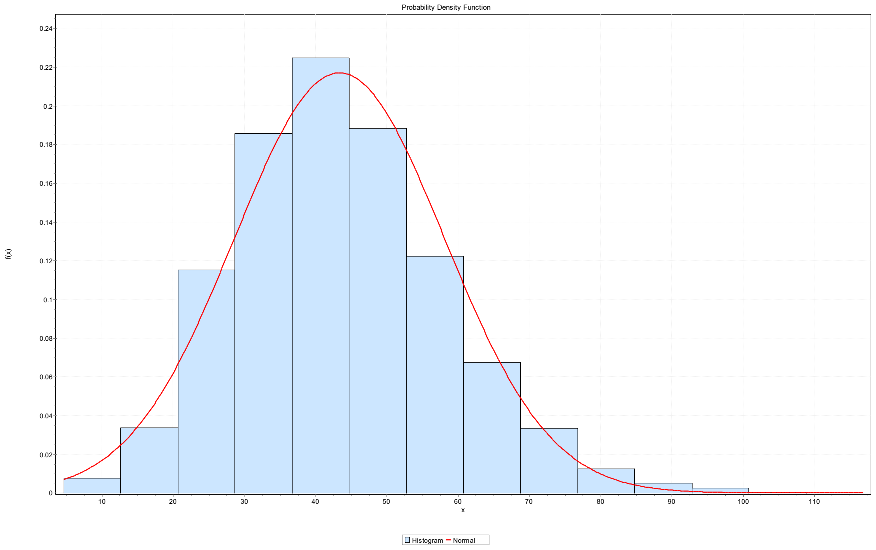

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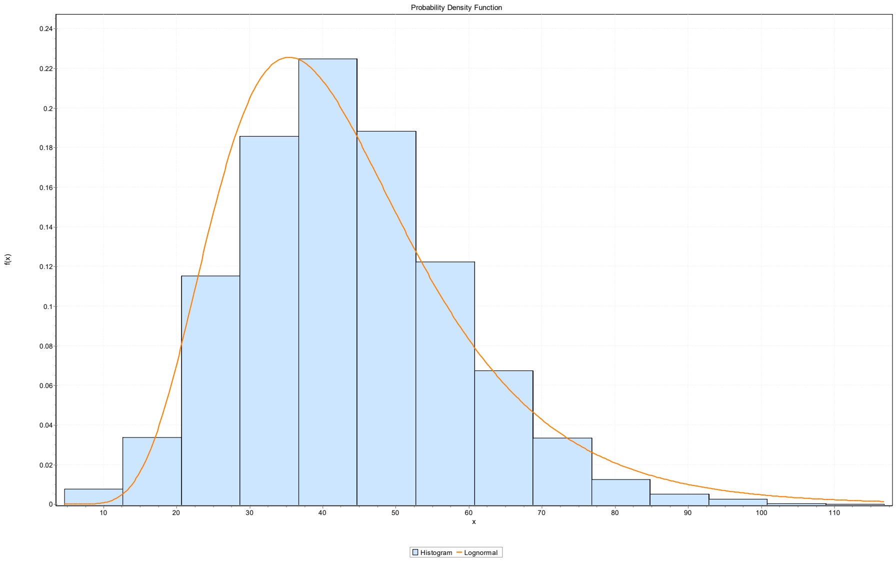

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