University of Southern Queensland
Faculty of Engineering and Surveying

Improving Accuracy of Rainwater Tank Hydrologic Yield Estimation across Queensland

A dissertation submitted by

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Abstract

This dissertation aims to increase the accuracy of rainwater tank hydrologic yield and water saving efficiency estimation throughout Queensland. Traditional methods of determining average annual hydrologic yield from average annual precipitation and water saving efficiency from seasonality indexation are reproduced using current daily observations from the Bureau of Meteorology (BOM). Limits with these methods are identified as reduced regression confidence and increased dependence on site parameters. An alternative method of performance indexation is presented based on the failure principles of a rainwater tank mass balance simulation. The Taylor’s Hyetology Index (THI) allows hydrologic yield and reliability to be determined independent of location or rainwater tank volume. THI provides higher regression confidence and reduces the current number of charts needed to represent Queensland from 90 to 9.

2520 unique simulations were conducted with Aquacycle to provide the data for state-wide trend discovery. These simulations are the result of placing a model unit block at eight sites being Birdsville, Brisbane, Cairns, Caloundra, Charleville, Mount Isa, Rockhampton and Townsville. The model unit block takes many forms defined by five parameter dimensions. The parameter dimensions include effective roof areas (75 m^2, 150 m^2 and 225 m^2), garden irrigation areas (Nil, 125 m^2 and 250 m^2), nominal rainwater tank volumes (3 kL, 5 kL, 7.2 kL, 10 kL and 14.5 kL) and occupancies of 1 to 7. Data drill BOM daily precipitation and FAO Penmam-Monteith potential evapotranspiration data for the period 01/01/1970 to 18/06/2009 was used for each site.

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I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

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Date

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Table of nomenclature

$\%GI$	Average % garden area
$A1$	The % area of pervious store 1
BF	Stormwater base flow
BI	Base flow index
BRC	Base flow recession constant
$clust_{area}$	Cluster area
C_{150}	Excess precipitation coefficient
C_{sw}	Consumption of water from a stormwater store
C_t	Tank volume regression coefficient
D_{dry}	Number of simulation days without precipitation
D_{150}	Number of simulation days with precipitation exceeding 150 mm
D_{total}	Total number of simulation days
E_a	Actual evapotranspiration
E_{imp}	Impervious surface evaporation
E_p	Potential evapotranspiration
E_{pc}	Plant controlled maximum evapotranspiration
ERA	Effective roof area
EXC	Precipitation excess
ff	First flush volume
GWR	Ground water recharge
GWS	Ground water storage level
I	Import water usage
In_{sw}	Inflow of stormwater into a stormwater store
IR	Garden irrigation requirement
$IRUN$	Impervious surface runoff

ISI	Runoff losses – wastewater system infiltration
IWU	Indoor water usage
LD	Leakage depth
$NEAR$	The proportion of impervious runoff that flows onto adjacent pervious areas
O_{sw}	Overflow of stormwater from a stormwater store
P	Precipitation
$PS1$	Pervious storage 1 level
$PS1_C$	Pervious storage 1 capacity
$PS2$	Pervious storage 2 level
$PS2_C$	Pervious storage 2 capacity
RIL	Roof area maximum initial loss
$roof_{area}$	Dwelling roof area
$\overline{R}$	Median annual precipitation
R_s	Stormwater runoff
RST	Roof surface storage level
S_t	Storage volume in a stormwater store at the end of the current time step
S_{t-1}	Storage volume in a stormwater store at the end of the previous time step
SI	Seasonality index
$SRUN$	Pervious surface runoff
TG	Garden trigger-to-irrigate ratio
THI	Taylor’s Hyetology Index
V_f	Failure tank volume
V_t	Nominal tank volume
X_j	Median monthly precipitation for month j

Glossary of terms and abbreviations

Hydrologic yield:	The volume of water extracted from a rainwater over time tank for domestic consumption
Water saving efficiency:	The hydrologic yield divided by the total domestic water consumption

ABS	Australian Bureau of Statistics
AWBM	Australian water balance model
BOM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSV	Comma separated values
DRIP	Disaggregated Rectangular Intensity Pulse
IEAust	Institute of Engineers Australia
eCRC	eWater Cooperative Research Centre
GBRMPA	Great Barrier Reef Marine Park Authority
IISR	Innovation, Industry, Science and Research Minister
MART	Multi-factor Analysis Water Tank model
MJA	Marsden Jacob Associates
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
FAOPM	FAO Penmam-Monteith potential evapotranspiration
PURRS	Probabilistic Urban Rainfall and wastewater Reuse Simulator
QWC	Queensland Water Commission
SI	Seasonality Index
THI	Taylor’s Hyetology Index
TRC	Toowoomba Regional Council
USQ	University of Southern Queensland
WSUD	Water sensitive urban design

Chapter 1

Introduction

The worst water shortage for South East Queensland on record is likely to be caused from poor resources management. The Queensland Water Commission (QWC) failed to anticipate low Wivenhoe and Somerset Dam inflows for the period 2000 to 2006. Historic dam inflow data (Thorstensen, Watt & Amghar 2007) shows dry periods of 5 years or more have occurred several times since 1890 and that the magnitude of the recent period is not excessive. Just how close South East Queensland came to serious trouble is obvious when reviewing historic dam capacities (Seqwater 2009) and the extent of water restrictions (QWC 2009). Recent inflow and relief has occurred for Brisbane and surrounds but, many Queensland areas such as the Darling Downs are still facing serious issues (TRC 2009). There are many that advocate the water crisis could have been avoided.

17.4% of Queensland households are fitted with rainwater tanks. Queensland is above the national average of 17.2% (ABS 2006) but, there is significant room for improvement. Brisbane’s household rainwater tank occupancy is 16% which is significantly behind the balance of the state 34% (ABS 2007). This is despite Brisbane being one of the top performing capital cities for rainwater tank water saving efficiency (Jenkins 2007). As this research will show, potable water savings in excess of 50% can be achieved through installing rainwater tanks in South East Queensland. Recent research shows that more than 80% of Brisbane households without rainwater tanks have considered installing a tank (ABS 2007). This provides an opportunity to reduce Brisbane domestic water consumption by 34% (installing rainwater tanks with 50% or higher water saving efficiency at 67% of Brisbane’s households). It is highly likely that engaging this strategy earlier coupled with water use education could have avoided or at least lessened the water crisis. The Federal Government support of this is highly evident in their last budget.

The Australian Government has recently offered, within their $1.5 billion urban water plan, 500 000 rainwater tank subsidies (CSIRO 2008). Providing subsidies on this scale gives great incentive for developers and homeowners to install rainwater tanks. The combination of environmental and financial incentives is significantly increasing social moral towards rainwater tank installation. As expected, rainwater tank sales have continued to rise (ABS 2008). Review of many regional water resources management strategies is now showing an increase to quantify the potable water savings derived from rainwater tank installations. The consequence of high demand and political acceptance provides social justification that rainwater tanks have a significant immediate and long term place in society. But benefits of rainwater tanks extend beyond reticulated potable water savings.

Conservation and value estimation research of wetlands and river ecosystems of international importance has occurred over many decades (Whitten et al. 2002). Presently, Australia lists 851 wetlands of international significance which cover almost 60 million hectares (Environment Australia 2001). These ecosystems are facing increasing habitat deprivation resulting from catchment change (Kingsford et al. 2009). This is supported by Walsh (2004) who reports urbanisation as a global threat to in-stream biota. Catchment change is also a key cause of degradation to the Great Barrier Reef (Brodie et. al. 2001). The economic contribution of the reef to the nation is in excess of $4.1 billion annually across the tourism, commercial fishing, cultural and recreation sectors (GBRMPA 2005). The magnitude of the environmental value is difficult to imagine. One major cause of degradation to wetlands, river systems and coral reefs is catchment modification through agriculture and urbanisation (Kingsford et al. 2009).

With urbanisation comes an increase in impervious area and modification to natural water courses (CSIRO 2006). In high density urban developments this catchment change substantially disrupts the water balance. The extent and process of remedial works is reported to be dependant on the increase in impervious area (Christopher et. al. 1999). The four main catchment changes affects are increased pollution, removal of the natural assimilation capacity to clean stormwater, removal of aquifer recharging and increased peak and volumetric stormwater discharge. Technology is emerging to remedy some catchment change affects.

Water sensitive urban design (WSUD) aims to recover the natural water balance, where possible, for existing urban development and to ensure future development design reduces catchment change consequences. A key step towards achieving this is inclusion of rainwater tanks. Research shows (Pezzaniti 2003) catchment wide benefits exist for inclusion of rainwater tanks in urban design. Rainwater tanks remove stormwater from the system by discharging to the sewer through in-home use. This can mitigate peak and volumetric stormwater discharge and pollutant discharge. Tanks also help to recharge the groundwater through garden irrigation. But some questions remain. Do we know with accuracy what size rainwater tank should be installed to meet desired efficiency and reliability performance? Do we also need to know what a reasonable reliability performance for our region is?

The current federal budget includes $512 million for sustainable research excellence in universities (IISR 2009). The magnitude of this investment strongly places sustainability as a priority for current and future education and engineering practices across all disciplines. It also emphasises that our present knowledge on this topic has many other unanswered questions. The importance of sustainable engineering is reinforced by the Institute of Engineers Australia’s Code of Ethics (IEAust 2000). This research is focused on sustainable engineering in the context of rainwater harvesting. The technical, environmental and social research aims and consequential affects are evident of this.

1.1 Research Aims

This technical aim of this research is to improve the accuracy and relevance of rainwater tank hydrologic yield and water saving efficiency estimation within Queensland. The scope of investigation will extend to envelope the majority of current and emerging developments found and the climate classification that exist within the state. The results will be presented in a series of straightforward graphs suitable for application by developers and homeowners. By increasing the relevance and accuracy of the body of knowledge this research is also intended to bring environmental and social benefits.

The environmental aim of the research is to promote efficient rainwater harvesting to alleviate potable water consumption and mitigate peak and volumetric stormwater discharge and pollution discharge for any location in Queensland. By increasing accuracy and relevance beyond the present knowledge, more recognition of this technology should be forthcoming from authorities. This recognition will increase environmental standing which can only enhance sustainability environmental engineering for future urban development.

The social aim of this research is to improve community confidence by providing relevant, accurate and straightforward information to those seeking the environmental benefits of rainwater harvesting and reducing catchment change. Increasing community confidence is the key to employing any new technology. At present, a surge of innovative environmentally conscious engineering projects exists and this research intends to contribute to and enhance this evolution.

1.2 Research objectives

To achieve these research aims, specific objectives are listed as:

- Review literature to establish key research results, available simulation programs, methods for simulation program selection, points of conflicting opinion and grounds for project work.
- Rank the short list of rainwater tank mass balance simulations programs discovered from the literature review to determine the most appropriate for this research.
- Review the functions of highly ranked simulation programs to determine program ability to meet research aims within resource limitations.
- Review the assumptions and cautions of the highly ranked simulation programs to ensure the quality of research output is not compromised.
- Calibrate and validate highly ranked simulation programs against key research results discovered from the literature review to facilitate review of research processes and results.
- From review of functions, assumptions, cautions and validation results determine, acquire and learn the chosen simulation program and supporting material.
- Define all input parameter to be used during simulation to ensure results are relevant to current and emerging developments and alike present research to facilitate research review.
- Determine key study sites to represent the climate classes and to provide a good spatial dispersion throughout Queensland.
- Acquire and review Bureau of Meteorology (BOM) daily precipitation and potential evapotranspiration data sets for each study area.
- Detail the research level assumptions to ensure appropriate application of research results can be measured.
- Reproduce key research results using current BOM data to benchmarks to review research results.

- Determine alternative methods for yield and efficiency performance indexation to achieve improvement over research benchmarks.
- Determine the dependence of household occupancy, roof area, tank volume and garden irrigation area on hydrologic yield and water saving efficiency and present results in a straightforward means.
- Identify opportunities for future research work.

Chapter 2

Literature Review

Being a desktop project focused on data analysis, a significant portion of research work and time was devoted to simulation and analysis. To ensure the simulation processes and results could be easily reviewed, a simulation environment was established alike leading researchers in the field. A detailed review of current research was essential to identify the knowledge gap this research aimed to overcome and the foundation from which research would began.

The review focused on the following key areas:

- Types of rainwater tank simulations;
- Simulation programs employed;
- Guidelines for choosing a simulation program;
- Typical parameter values and environmental observation data adopted;
- Key research results suitable for calibration, validation and performance benchmarks; and
- Current guidelines and rebates for rainwater tank selection.

2.1 Types of rainwater tank simulations

The variety of simulations that can be discovered is vast. The two greatest distinctions are the scope of simulation and the form of results. The scope of simulation can vary from national to single city to single dwelling. Results take on many forms of yield and efficiency.

The most conclusive research found (MJA 2007) provides a commanding national study where annual tank yield is derived from roof area, tank size, occupancy, annual rainfall, climate scenario and rainfall pattern. The research represents Queensland, New South Whales, Victoria, South Australia and Western Australia by their capital cities. The range of input parameters provides an impressive consideration of climate classes and development types that exist nationally. However, the application of the research is limited by suggesting the performance of each capital city well-represents that of their corresponding state, which this research shows to be otherwise. Furthermore, results are presented using two figures only. If considering a situation that differs in more than one way to the base case these figures become difficult to decipher without an engineering background. This study is very comprehensive but fails to present results in a form that is relevant to those purchasing rainwater tanks.

enHealth (2004) has conducted a very comprehensive national study where they report rainwater tank volumes to provide 90% or 99% water security. Volume is determined from annual rainfall, daily consumption and roof area. The range in consumption and roof area envelopes a commanding number of development types; however, their method fails to incorporate the seasonal variation of consumption, particularly when external irrigation is considered. It is uncommon to see the peak in annual consumption coincide with the time of peak annual rainfall. Failure to include the seasonal variation could lead to moderate errors in results. Also, there are significant limitations when using annual rainfall as a selection parameter. This research demonstrates that high annual rainfall doesn’t ideally relate to high rainwater yield. This would also introduce moderate errors in results. The compounding errors would reduce the application of enHealth’s results to the specific region where simulation was conducted; however, enHealth fails to disclose this, which provides little real application. There are some studies that provide more tangible results.

Jenkins (2007) falls short of a complete national study by only including sites from New South Whales, Queensland, Victoria, Northern Territory and Western Australia but does include a mix of capital and regional cities. Jenkins, like enHealth, presents reliability results, but uses the term water saving efficiency and hydraulic effectiveness. Jenkins' water saving efficiency is identical to the definition adopted by this research and means the same as enHealth's reliability. Hydraulic effectiveness is the ratio of consumed runoff to total runoff. Jenkins' method like enHealth fails to allow for seasonal variation in consumption, but he overcomes the limitation of using an annual rainfall domain by adopting a Seasonality Index (SI). Jenkins details the method to calculate SI for any site which allows unrestricted geographic application of his research.

Coombes and Kuczera (2003) also fall short of a national study by only including Queensland, New South Whales, Victoria and South Australia by their capital cities alone. Coombes presents yield and retention storage results. Coombes' yield holds the same definition as hydrologic yield for this research. Retention storage is the storage volume available prior to rainfall. Coombes overcomes the limitation of constant consumption by providing the monthly variation for indoor and outdoor consumption pertinent to monitored usage behaviour. Coombes adopts a tank volume domain and a series of graphs being for various effective roof areas and locations. This present a new limitation as the tank performance for a capital city can not be applied over its state with accuracy. This restricts the application of the research to the capital cities included and surrounds.

Phillips et. al. (2004) studies the introduction of rainwater tanks in Caloundra West and Maleny, Queensland. Phillips presents his yield calculations as water utilisation and provides a graphical means of determining efficiency. Phillips overcomes the limitation of constant consumption by adopting a daily varying consumption for external consumption and constant for indoor consumption. As Phillips' results are restricted to one region he presents a tank volume domain. Phillips' is specific to Caloundra West and Maleny and therefore has limited state wide application.

Coombes and many others have studied individual sites such as Carrington, Newcastle (Coombes et. al. 2004). Results from these studies are highly specific to the configuration and reveal little understanding of the performance of the location under different site conditions.

2.2 Simulation programs used in the field

The four most common simulation programs used in the field were identified as Probabilistic Urban Rainfall and wastewater Reuse Simulator (PURRS), Model for Urban Stormwater Improvement Conceptualisation (MUSIC), Aquacycle and Excel programming.

PURRS was developed by Dr P Coombes from Newcastle University and has been adopted by many researches. PURRS uses a six minute time step for both precipitation and consumption. PURRS is widely considered as the leading rainwater tank simulation program and as such has been extensively used. PURRS is packaged with pluviograph data. This negates the need to create synthetic six minute data from BOM data sets using Disaggregated Rectangular Intensity Pulse (DRIP) for many locations.

MUSIC is developed and distributed by eWater Cooperative Research Centre (eCRC). MUSIC is widely used mainly due to the capacity to simulate WSUD element configured as a single element or complete treatment train. MUSIC also adopts a six minute precipitation time step, but a daily time step for consumption. Lucas, Coombes and Geary (n.d.) reports the shortcomings of this method.

Aquacycle was developed by G Mitchell and is distributed by eCRC. Aquacycle is a gaming tool for predicting water consumption from a variety of sources. Aquacycle is ideal for rainwater tank simulation and has been used for many applications.

Excel programming was common among the less sophisticated simulations, but has the capacity to be developed inline with the performance of the other key programs.

There are many other programs available such as RainTank developed by Griffith University. Jenkins (2007) was the only research found to be using RainTank and as the program was not readily available it was not considered further. Also Multi-factor Analysis Water Tank model (MART) developed by MJA. This program was also not readily available and not considered further.

2.3 Guidelines for simulation program selection

As selecting a simulation program was the principal decision for this research project. Advice on selection was considered. Two key references (CRC 2005a) and (CRC 2005b) report guidelines for simulation program selection. The guidelines detail the criteria to be assessed to increase the relevance and accuracy of results and the chance of completing simulation within resource restrictions.

2.4 Typical parameter values and environmental observation data adopted

To facilitate review of research processes and results, parameter values were chosen alike current research, where possible. The parameter values are best tabulated. Refer to Table 2.1.

2.5 Key research results for calibration, validation and performance benchmarks

It is apparent from reviewing the previous sections of this chapter that key research results can be identified to provide calibration, validation and performance benchmarks. Coombes was chosen due to an extensive readership. Coombes also presents findings with a series of graphs where specific results can be accurately and readily obtained. Coombes' yield results will be used for calibration, validation and setting performance benchmarks for hydraulic yield results.

Similarly Jenkins' efficiency results will be used for calibration, validation and setting performance benchmarks for water saving efficiency results.

Table 2.1 Parameter values used in current research

Parameter	**MJA**	**enHealth**	**Coombes**	**Jenkins**
Rainwater tank volumes (kL)	2, 5, & 10	3 – 51	1, 2.5, 5, 7.5 & 10	1, 5, 10.5, 15 & 24
Roof Areas (m^2)	50, 125 & 200	100, 150, 200, 300, 400, 500 & 600	100, 150 & 200	200
Consumption (L/d)	1, 2, 4 & 6 occupants plus outdoor irrigation	60, 100, 200 a& 400 (L/day)	1 – 5 occupants plus outdoor irrigation	110, 257, 323, 433, 580, 675 and 734 (L/day)
Time series rainfall data	100 years of daily BOM observations	Daily BOM observations. (duration unconfirmed)	100 years of 6 minute synthetic data ending 2002	113 years of daily BOM observations ending 2003

2.6 Guidelines for tank system selection

Federal advice (DEWHA 2009) on tank selection, provided to support the rebate scheme, fails to quantify water saving efficiencies from the various site specific parameters. The guidelines offer limited examples and recommendations are restricted to adopting tank volumes either above or below 10 kL. The Federal domestic rebates scale is determined, among other criterion, on tank size either above or below 4 kL (DEWHA n.d.). This demonstrates the rebate scheme fails to follow the supporting tank volume recommendations. As a result, a financial disadvantage exists when adopting medium to large volume rainwater tanks (above 4 kL), which directly contradicts the aim of reducing reticulated potable water consumption.

The Queensland Government manages to move further from encouraging implementation of rainwater tanks by terminating their rebate scheme as of June 2009.

2.7 Summary

The quantity and quality of research information available on this topic is substantial. This research will analyse the simulation programs used to determine the most appropriate. The range of input parameter values used will be investigated to adopt a parameter set that is as common as possible to facilitate review of results. Key research results have been adopted from Coombes and Kuczera (2003) and Jenkins (2007) for us calibration, validation and assessing research results against performance benchmarks.

Although there is extensive current research on this topic the key gap in the knowledge base have been identified as: Failure to represent all climate classes and the majority of current and emerging developments within Queensland, in the once conclusive study that presents tank selection guidelines in a fashion that is pertinent those purchasing rainwater tanks.

Chapter 3

Methodology

Research was undertaken using a two phased approach. Phase one focused on rainwater tank mass balance simulation and phase two focused on state-wide hydrologic yield and water saving efficiency trend discovery.

The process of completing the simulation phase followed four main steps:

- Selecting, learning, calibrating and validating a simulation program;
- Defining all input parameters;
- Establishing the variation in unit block configuration to be adopted for all simulations; and
- Conducting all simulations to allow the second research phase of trend discovery to commence.

The procedure adopted to complete each step will be discussed inturn.

3.1 Choosing a simulation program

The first and principal research decision was the choice of simulation program, so the procedure adopted to complete this will be explained in full. A simulation program was determined using five main steps:

- Determine a short list of suitable simulation programs discovered from the literature review;

- Analyse the short list of programs using performance criteria to rank by research suitability;
- Undertake a detailed review of the functions within each program, starting from the top ranked program, until a program is found to meet the research objectives;
- Confirm the program assumptions and cautions are unlikely to detract from the research quality; and
- Calibrate the program and validate output. If output is accurate then adopt the program.

The process of choosing the simulation program is shown in Figure 3.1

3.1.1 Simulation program short list

Programs short listed from the literature review to undergo a detailed assessment against project relevance criteria are:

- Aquacycle (Developed by Grace Mitchell)
- MUSIC (Developed by eWater Cooperative Research Centre)
- PURRS (Developed by Dr P Coombes)
- Microsoft Excel programming (Specific to this research)

In order to rank the research relevance of these program an assessment criteria was established.

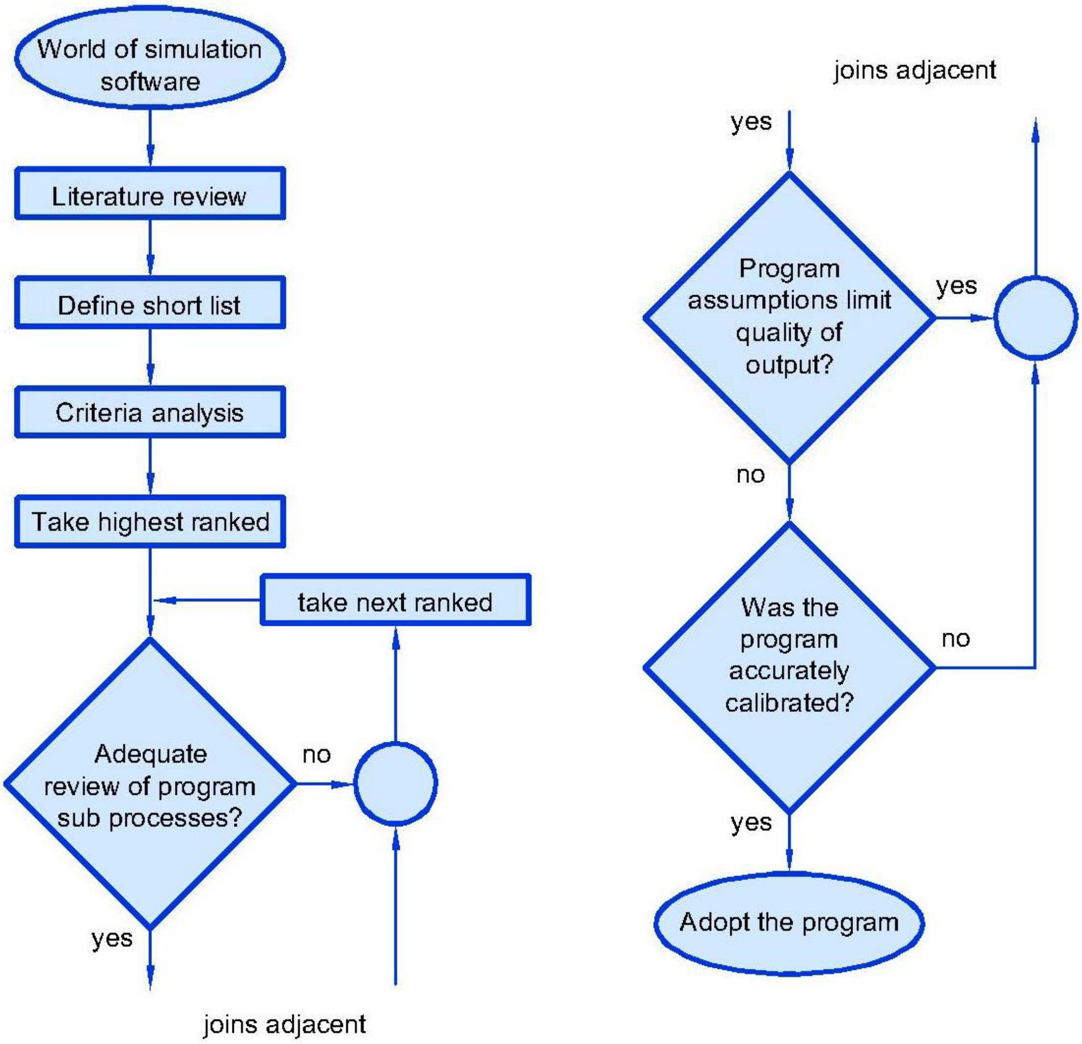

Figure 3.1 Choosing a simulation program

3.1.2 Program assessment criteria

A large variety of programs are capable of simulating the mass balance of a rainwater tank over time. A detailed assessment of suitable programs was undertaken to determine the most appropriate for this research. The measure of appropriateness was determined using weighted performance criteria.

The ability for the program to address each criterion was measured on a performance scale of 1 to 5. This scale represents abilities of:

1. Poor;
2. Limited;
3. Average;
4. Good; and
5. Excellent.

The criteria importance weightings were determined using a scale of 1 to 6. This scale represents the criterion influence on meeting the resource restrictions and desired output quality.

The scale represents importance being:

1. Some consideration should be given as may increase research but, without affecting output quality.
2. Some consideration should be given to ensure research can be completed within resource allocation and reduction to output quality does not occur.
3. Consideration needed to ensure research can be completed within resource limits.
4. Important to the quality of results and without may be difficult to justify conclusions but not expected to increase research.
5. Important to the overall research and without may create significant additional work and limit output quality.
6. Fundamental to the overall research and without would be very difficult to accurately complete within resource constraints.

The criteria importance weightings were applied to each criterion and then scaled to represent unit weighting where the sum of criterion weight equals 1.

Of the collection of programs available Aquacycle, MUSIC and PURRS together with programming (using Microsoft Excel) was chosen for further analysis. Excel programming would involve reproducing the rainwater tank mass balance simulation from the fundamentals knowledge gained through analysing the other programs. Refer to Table 3.1 for the performance criteria, unit weights and weighted scores.

The first criterion is the ability of the program to meet the research objectives. This is fundamental to the overall research and without would be very difficult to accurately complete. This criterion was the measure used to determine which applications should be short listed for reviewed against the criteria matrix. It can be seen in Table 3.1 that all programs scored excellent for this criterion.

Table 3.1 Simulation program performance criteria and weighted scores

Criteria	**Wt.**	**Aquacycle**		**MUSIC**		**PURRS**		**Excel**	
		rate	score	rate	score	rate	score	rate	score
Meet research objectives	0.17	5	0.86	5	0.86	5	0.86	5	0.86
Cost	0.07	5	0.36	3	0.21	1	0.07	5	0.36
Time step	0.04	3	0.13	5	0.21	5	0.21	5	0.21
Data requirements	0.14	5	0.68	3	0.41	3	0.41	3	0.41
Simulation runtime	0.07	5	0.36	3	0.21	3	0.21	4	0.29
Presence in field	0.11	4	0.43	4	0.43	5	0.54	1	0.11
Published parameter values	0.14	4	0.54	4	0.54	5	0.68	1	0.14
Model accuracy	0.04	4	0.17	5	0.21	5	0.21	2	0.09
Ability to calibrate / validate output	0.11	4	0.43	4	0.43	5	0.54	1	0.11
Model classification	0.02	5	0.11	5	0.11	5	0.11	5	0.11
Spatial and temporal output resolution	0.02	5	0.11	5	0.11	5	0.11	5	0.11
Modeller expertise needed	0.07	5	0.36	5	0.36	5	0.36	1	0.07
Weighted total	**1.0**		**4.52**		**4.09**		**4.30**		**2.84**

The program acquisition and support cost is considered important to ensure research can be completed within resource limits. Aquacycle and Excel programming both have no acquisition or support cost which rates them excellent. MUSIC costs $300 plus BOM data. It was suggested that the research budget could be increased to cover this and was rated average as additional costs may be encountered. The acquisition and support cost of PURRS is $800 which includes data. This is well beyond the research budget and as such was rated poor.

The simulation time step was considered to ensure research can be completed within resource allocation and reduction to output quality does not occur. With most mass balance simulation programs the smaller time step generally increases the accuracy of results but at the cost of increasing simulation runtime. Aquacycle rated average as daily inflow and outflow has restricted accuracy but, this time step is well adopted by current research. MUSIC, PURRS and Excel programming rated excellent as a sub-daily time step of 6 minutes could be used and this would generally increase model accuracy.

The data requirement was considered important to the overall research and without consideration may create significant additional work and output quality limitations. Aquacycle rated excellent due to the daily time step. Daily precipitation and potential evapotranspiration data is readily available from the BOM for durations in excess of 20 years for all sites across the scope of research. MUSIC, PURRS and Excel programming rated average due to the sub-daily time step. Sub-daily precipitation and evapotranspiration BOM data is limited in temporal and spatial resolution and would need to be synthetically produced. It is possible that these limits may reduce the ability to discover any state-wide trends or increase project work beyond time restrictions.

Simulation runtime was considered to ensure research can be completed within resource limits, in this case time constraints. Aquacycle rated excellent as seven simulations could be conducted in less than 30 seconds. MUSIC and PURRS were rated average as their runtimes were significantly larger relative to Aquacycle.

Spreadsheet programming rated good as simulation was also less than 30 seconds but, would require manual calculation which can create confusion and errors.

The presence of the program in the field of research was considered important to the quality of results and without may be difficult to justify conclusions. This is largely due to maintaining similarity between studies which allows easier review of research processes and results. Aquacycle and MUSIC were rated good as there are numerous studies where simulation was conducted using these programs. PURRS rated excellent due to the extensive work of Dr P Coombes. Excel programming rated poor as specialised software has only the presence that this idea was adopted by few researchers but, the program itself would be entirely unique to this research.

Published parameter values are considered important to the overall research and without may create significant additional work and limit output quality. Simulation programs require inputs and in this case the lists are extensive. Published values can prove highly useful to hit the ground running rather then extending the scope of research to include fundamental knowledge usually derived from empirical studies. Aquacycle and MUSIC were rated good due to the comprehensive user manuals provided and discussion forums established by the software distributors, eWater Cooperative Research Centre (eCRC). PURRS rated excellent due to the extensive data provided with the software and having email access to the creator Dr P Coombes. Excel programming rated poor as discovery of input parameters would extend the research scope.

Model accuracy was considered to ensure research can be completed without reduction to output quality. Model accuracy was largely discussed through the time step criterion but will be extended here. Aquacycle rated good for accuracy as the results are expected to be of less quality then simulations using a sub-daily time step but, of an accuracy that is suitable for state-wide trend discovery. MUSIC and PURRS rated excellent due to the sub-daily time step; however, this score is only slightly better than Aquacycle as the amount of synthetic data needed to conduct the simulation is significantly higher than Aquacycle. The advantage of the smaller time step is reduced through the increased dependence on synthetic data which holds numerous assumptions. Spreadsheet programming rated limited as extensive programming and testing of functions is unlikely given the research time constraints.

Published calibration and validation data was considered important to the quality of results and without may be difficult to justify conclusions. Calibration and validation was largely covered in the presence in field criterion but, will be extended here. Aquacycle and MUSIC rated good as numerous studies were conducted where simulation used these applications. These studies used simular input parameters to those adopted by the research which simplifies the calibration and validation process. PURRS rated excellent due to the extensive work undertaken by Dr P Coombes and other researchers. Excel programming rated poor due the exclusivity offered. Spreadsheet calibration and validation could only be achieved through monitoring output against other calibrated studies of similar simulation processes. This is considered to be a difficult and time consuming.

Model classification and spatial and temporal output resolution were largely considered during short listing of programs for criteria assessment. These criteria are discussed here for completeness. The process undertaken beyond simulation will be discussed in chapter 4, but it is noteworthy to state the trend discovery will be undertaken using alternate software once simulation is complete. This simplifies the program classification needed to ‘deterministic conceptual models with low spatial and low temporal output resolution’. As all applications considered are deterministic conceptual models with high spatial and high temporal output resolution they all rate excellent.

Modeller expertise needed was considered to ensure research can be completed within resource limits, mainly staffing. Aquacycle, MUSIC and PURRS were rated excellent as the level of expertise needed would be that of a graduate engineer. Spreadsheet programming rated poor as an increased level of expertise would be needed to cover the significant programming and testing requirements.

3.1.3 Program assessment results

From the weighted totals of each program it can be seen that Aquacycle scores highest (4.52) making it the first simulation program choice. It should be noted that PURRS was a close second (4.30) and this was due to the acquisition cost. If the functions, assumptions and cautions of Aquacycle were found to detract from the research objectives then PURRS would have been investigated further. Excel programming was least appropriate scoring last (2.84).

To confirm Aquacycle ability to perform rainwater tank mass balance simulation a detailed review of functions, assumptions, limits and cautions was undertaken.

3.2 Aquacycle assessment as a rainwater tank simulator

Aquacycle, developed by Grace Mitchell, is a gaming tool for prediction of water consumption from a variety of sources. Aquacycle provides a temporal scale range including daily, monthly and yearly and a spatial scale range including unit block, cluster and catchment. Aquacycle does not consider water quality. Aquacycle temporal scale will be limited to annual output only and the spatial scale investigated will be unit block only. Aquacycle functions are detailed within the user manual (Mitchell 2005).

These functions and their research relevance will be briefly discussed.

Aquacycle functions include:

- Stormwater;
- External irrigation;
- Evapotranspiration;
- Residential indoor water usage;
- Reticulation system leakage and imported water;

- Wastewater discharge;
- Impervious surface storage;
- Pervious surface storage;
- Groundwater storage operation;
- Stormwater storage operation;
- Wastewater treatment, storage and operation;
- Aquifer storage and recovery operation;
- Performance assessment; and
- Storage optimisation.

3.2.1 Stormwater function

The stormwater function is relevant to the research as external water use for garden irrigation will be included to envelope developments where garden irrigation is needed. The stormwater function is used to increase the moisture content of the garden bed. Aquacycle uses a two component stormwater model of surface flow and base flow. Surface runoff is contributed from four surface types being pervious, rooves, paved and roads.

The stormwater runoff (R_s) is determined by the equation:

$$R_s \quad = \quad IRUN + SRUN + BF - ISI \tag{3.1}$$

Stormwater runoff is the contribution due to impervious runoff (*IRUN*), pervious runoff (*SRUN*), base flow (*BF*) and wastewater infiltration losses (*ISI*). Each will be explained inturn, excluding *ISI* as it is considered immaterial for this research. For variables refer nomenclature.

The contribution due to impervious runoff is simplified by adopting nil road runoff and nil paved runoff from the system. This configuration was adopted on the assumption that once stormwater reached the paved surface (driveway) it would immediately discharge to the stormwater system or road surface and from either it would not return to the residential block. Furthermore, the research scope is limited to one single residential block not the interaction of a cluster or catchment of residential blocks.

The impervious runoff is determined by the equation:

$$IRUN \quad = \quad ERA.(P - RIL + RST).(roof_{area} / clust_{area}) \tag{3.2}$$

The amount of impervious runoff that flows onto adjacent pervious areas (*NEAR*) is determined by the equation:

$$NEAR \quad = \quad (100 - ERA).(P - RIL + RST).(roof_{area} / clust_{area}) \tag{3.3}$$

This important function simulates the gutter system overflowing onto the pervious surface below which frequently occurs in residential developments in Queensland.

Modelling of pervious surface runoff and base flow follows the Australian Water Balance Model (AWBM) (Boughton 1993). The excess soil moisture (*EXC*), or rainfall excess, is determined by the equation:

$$\begin{aligned} EXC \quad = \quad & \{\max(P + PS1 - PS1_C, 0)\}.A1 \\ & + \{\max(P + PS2 - PS2_C, 0)\}(100 - A1) \end{aligned} \tag{3.4}$$

Following AWBM the ground water store (*GWS*) is drained according to the recession function which creates base flow (*BF*). This is determined by the following two equations:

$$GWR \quad = \quad BI.EXC \tag{3.5}$$

$$BF = BRC.GWS \tag{3.6}$$

As infiltration into the wastewater system is considered immaterial and therefore not included in this research. The volume of pervious surface runoff which contributes to the total pervious stormwater flow ($SRUN$) is the combination of excess soil moisture less groundwater recharge and is determined by the equation:

$$SRUN = EXC - GWR \tag{3.7}$$

3.2.2 External irrigation function

The external irrigation function is relevant to this research in order to simulate the action of watering the garden when the soil moisture drops to a lower threshold. The garden irrigation requirement (IR) is the amount of irrigation required in the absence of precipitation to maintain the desired moisture content of the garden bed. The trigger to irrigate ratio (TG) is the lower soil moisture threshold at which irrigation occurs.

This function is determined by the equation:

$$\begin{aligned} IR = {} & \max\left(TG.PS1_C - PS1,0\right).A1.\%GI \\ & + \max\left(TG.PS2_C - PS2,0\right).\left(100 - A1\right).\%GI \end{aligned} \tag{3.8}$$

3.2.3 Evapotranspiration function

The evapotranspiration function is important to this research to allow distinct site changes in soil moisture levels accountable to higher evapotranspiration rates that exist in arid and northern regions. The actual evapotranspiration is determined from the soil moisture conditions and the potential evapotranspiration values measured by the BOM.

This function is determined by the equation:

$$\begin{aligned} E_a &= A1.\min\left\{\left(PS1/PS1_C\right).E_{pc}, E_p\right\} \\ &\quad + \left(100 - A1\right).\min\left\{\left(PS2/PS2_C\right).E_{pc}, E_p\right\} \end{aligned} \tag{3.9}$$

Emptying, due to evaporation, of the impervious surface store is determined by the equation:

$$E_{imp} = \max\left(E_p, RST\right).\left(roof_{area}/clust_{area}\right) \tag{3.10}$$

3.2.4 Residential indoor water usage function

The residential indoor water usage function is important to this research to incorporate the variation of dwelling occupants, and inherent water consumption, which exists from the development types within Queensland. Aquacycle uses a matrix of occupancies and indoor water facilities to account for the consumption variation. This matrix is further explained in Section 3.8.9.

3.2.5 Reticulation leakage and imported water function

Reticulation system leakage is not considered in this research due to the scope being limited to a single residential allotment. Furthermore the process of applying this research involves estimating the reduction in reticulated water usage as a result of installing rainwater tanks. This water saving can then be reduced from the current reticulated water demand, which if known, already includes losses due to theft and leakage.

The amount of imported water (I) is determined as the combination of indoor water usage (IWU) and garden irrigation requirement (IR) by the equation:

$$I = IWU + IR \tag{3.11}$$

3.2.6 Wastewater discharge function

The wastewater discharge function is not relevant to the research.

3.2.7 Impervious surface storage function

The impervious surface storage function is important to this research as it determines the antecedent condition of the roof surface prior to precipitation by the equation:

$$RST_t = RST_{t-1} + P - E_{imp}^{roof} - IRUN^{roof} - NEAR^{roof} \tag{3.12}$$

3.2.8 Pervious surface storage function

The pervious surface storage function is important to this research due to being part of the AWBM. The pervious surface storage for each store is determined using the equation:

$$PS1_t = PS1_{t-1} + P + IR + NEAR - E_a^{PS1} - EXC^{PST} \tag{3.13}$$

3.2.9 Groundwater storage operation function

The ground water storage function is important to this research due to being part of the AWBM and is determined by the equation:

$$GWS_t = GWS_{t-1} + GWR + LD - BF \qquad (3.14)$$

3.2.10 Stormwater storage operation function

The stormwater storage operation function is essential to this research as this function is used to simulate the mass balance of the rainwater tank.

The stored water available for use is determined by the equation:

$$S_t = S_{t-1} + In_{sw} - ff - C_{sw} - O_{sw} \qquad (3.15)$$

Refer Figure 3.2 for schematic elevation of the rainwater tank. Tank dimensions adopted in this research are detailed in Table 3.7.

3.2.11 Wastewater treatment, storage and operation function

The wastewater treatment, storage and operation function is not relevant to this research.

3.2.12 Aquifer storage and recovery operation function

The aquifer storage and recovery operation function is not relevant to this research

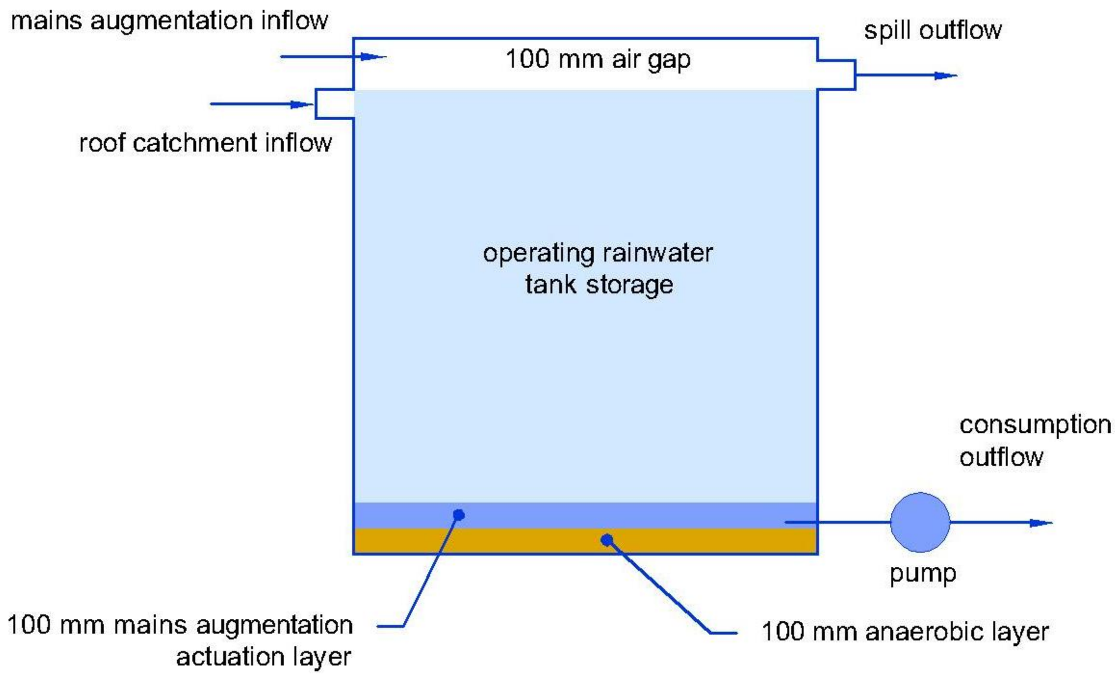

Figure 3.2 Schematic elevation of the rainwater tank

3.2.13 Performance assessment function

The performance assessment function is not relevant to this research

3.2.14 Storage optimisation function

The storage optimisation function is not relevant to this research.

3.3 Functions assessment results

It can be seen from the extensive list of detailed function adopted by Aquacycle that this comprehensive water balance program is rigorous enough to undertake the research simulation requirements.

3.4 Aquacycle assumptions and cautions assessment

The following assumptions and cautions are taken for the Aquacycle user manual (Mitchell 2005). The relevance of each to this research will be discussed.

3.4.1 Assumptions

> “The input and output of water occurs in a set order each day. Precipitation is added to and actual evaporation is removed from the two soil moisture stores simultaneously at the beginning of the day. Any moisture in excess of the soil storage capacity is then separated into surface runoff, groundwater recharge, and infiltration into the wastewater system. The irrigation demand is calculated and is applied at the end of the day.”

This is a general process used to apply the AWBM over a daily time step. Here the AWBM is extended to determine the irrigation demand. As discussed previously, a daily time step is not expected to limit the state-wide trend discovery that will occur following the Aquacycle simulation phase of the research. Therefore, this assumption is accepted.

> “Only one wetting and drying cycle occurs within a day. In reality, there may be multiple wetting and drying cycles, due to multiple rain events occurring within the day.”

The research relevance of this is covered in the preceding assumption; but, here reference to the shortcomings of the daily time step is direct. The drying cycle refers to evapotranspiration of the soil stores and consumption from the rainwater tank. Both of these processes in reality follow a diurnal pattern rather then occurring at a single point in time after precipitation. This is not expected to reduce the quality of this research. Therefore, this assumption is accepted.

> "It is assumed that effect of wind turbulence due to increased surface roughness, sheltering by buildings, and other microclimate variations due to urbanisation, does not have a significant impact on the accuracy of the method used to calculate actual evapotranspiration from pervious areas and evaporation from impervious areas. There is little known about the actual difference between urban and non-urban evapotranspiration."

Due to insufficient information on the effects of urbanisation on evapotranspiration this assumption is widely accepted.

> "Actual evapotranspiration of pervious areas varies depending on the soil moisture storage at the beginning of the day, and the evaporative demand estimated by potential evapotranspiration as supplied in the climate input file. This accords with the approach of AWBM."

This AWBM process is widely accepted under these circumstances.

> "The maximum rate of evaporation from the impervious surface is assumed to be given by potential evapotranspiration as supplied in the climate input file. No allowance is made for the effect that the heating of impervious surfaces has on the actual evaporation rate. Evaporation is removed from the impervious surface store at the end of the day (effectively after the rain event)."

Considering only rooved impervious surfaces are included in this research this assumption would have an immaterial affect. Therefore, this assumption is accepted.

> "Precipitation is spread evenly over the entire area with no variation due to wind turbulence and localised storms."

This research is centred on the performance of a single residential block of 900 m^2 and as such the assumption of evenly distributed precipitation is accepted.

> "Precipitation and irrigation wets the entire root zone to a constant level. This assumes the moisture is instantaneously distributed throughout the root zone when, in reality, a wetting front forms and the soil is slow to reach a constant soil moisture level throughout."

Inclusion of hydraulic conductivity of the soil is beyond the scope of this research. Therefore, this assumption is accepted.

> "Surface ponding and overland flow do not occur until the soil moisture storage capacity of the partial representative area is exceeded. This may over-estimate the ability of precipitation and irrigation to wet the soil profile and underestimate runoff in intense rainfall events when infiltration capacity of the soil profile is exceeded."

This is an assumption inherited from the AWBM and is widely accepted under these circumstances.

> "The maximum initial loss from an impervious surface and the effective impervious area is assumed to be a fixed constant throughout the rain event and for all seasons during the year."

Roof initial losses are set to 1 mm and the seasonal variation is expected to be immaterial. Therefore, this assumption is accepted.

> "Non-effective area paved area runoff spills onto the pervious area within the same unit block."

As no paved areas are included in this research this assumption is irrelevant.

> “When there is a pervious area (garden) within the unit block, half of the non-effective roof area runoff spills onto the pervious area within the same unit block while the other half flows into the cluster scale stormwater system. When there is no pervious area within the unit block, the entire non-effective area roof flows into the cluster scale stormwater system.”

This assumption replicates the use of a portion of guttering systems discharge to irrigate pervious areas as typically found in Queensland. It is debatable that as much as half of the roof area not connected to the rainwater tank will be used in this way; however, some portion needs to be included and for this reason this assumption is accepted to not significantly detract from the irrigation demand accuracy.

> “Any road runoff from unconnected areas (non-effective area) spills onto the whole of the public open space area within the cluster.”

As only unit block analysis is being considered this assumption is irrelevant.

> “The component of runoff from unconnected impervious areas that flows onto a pervious area is assumed to spread evenly across the entire adjacent pervious area (therefore being added to both pervious stores in equal areal depths). In actuality, the runoff would spill onto the edge of the adjacent pervious area and cause an increase in the moisture content of a small area.”

This is expected to slightly underestimate irrigation demand as the trigger to irrigate is activated simultaneously over the garden area rather then earlier from the driest point. The error from this process is expected to be within the accuracy limits of the simulation. Therefore this assumption is accepted.

> “If there is no pervious area adjacent to an impervious area, then the effective impervious area is 100%. All of the impervious surface must be

> directly connected to the stormwater system since there are no adjacent surfaces for the runoff to spill on to."

A pervious area is included in the unit block configuration adopted in this research. Therefore, this assumption is irrelevant.

> "There is no lateral movement of moisture in the soil profile. Therefore, there is no transfer of moisture between the two pervious stores. In addition, all soil below impervious surfaces is regarded as dry."

This assumption is inherited from AWBM and is widely accepted.

> "The groundwater store is assumed to be an unconfined aquifer."

Groundwater monitoring is not included in this research. Therefore, this assumption is irrelevant.

> "Groundwater recharge spreads uniformly over the entire groundwater store below a cluster; transmisivity is assumed to be infinite. Unless there is a large amount of water recharging at a fixed point within the modelled area, the assumption that there is no groundwater table gradient would have little impact on model accuracy. Any impact on base flow estimation is not significant enough to warrant more sophisticated modelling of the groundwater store."

The relevance of this is discussed with the previous response.

> "There is no deep seepage from the groundwater store. The only discharge from the groundwater store is through base flow."

The relevance of this is discussed with the previous response.

> “Part of the water applied to a garden will be wasted, since, depending on the timing of irrigation and the method used, part will evaporate before soaking into the soil or not available to the plant roots. However, the model assumes irrigation to be fully effective in recharging the soil moisture stores to the prescribed level with no wastage.”

This is expected to slightly underestimate irrigation demand; however, the error from this process is expected to be within the accuracy limits of the simulation. Therefore, this assumption is accepted.

> “All outdoor water use is due to irrigation of either gardens or public open space.”

Outdoor irrigation is limited to gardens only as public open space sustainability is beyond the scope of this research. This assumption is therefore accepted.

> “All road area is 100% impervious.”

Road surfaces are not included in this research as the scope is limited to a single residential block and catchment from a road surface is not expected to contribute to that residential block. This assumption is therefore irrelevant.

> “All public open space is 100% pervious.”

As no public space is included in this research this assumption is irrelevant.

> “The average annual year is 365.25 days in length.”

This assumption is widely accepted.

> “The initial storage level in the soil moisture stores is the greater of 0.5 x capacity or trigger-to-irrigate x capacity. It is calculated separately for gardens and open space in each cluster.”

This initial moisture stores condition is expected to have an immaterial affect on the average annual simulation over the 39 year period adopted by this research and is therefore accepted.

3.4.2 Cautions

If irrigation demand can not be met then the demand continues to compound until the trigger-to-irrigate threshold is reached. Under these circumstances Aquacycle is known to overestimate irrigation demand. Conversely, some assumptions show that under different circumstances, Aquacycle underestimates the irrigation demand. It is expected that the two contribute towards reducing the error from the irrigation function. Considering any error that does occur will be duplicated over all simulations, this caution is not expected to detract from the research objectives of state-wide trend discovery and is therefore accepted.

The rainwater tank mass balance follows the order of inflow, then supply, then spillage. This process tends to overestimate the usage or hydrologic yield of a rainwater tank. As discussed previously this is a limitation of the daily time step. This limitation is applied consistently over all simulations and will be considered during calibration. This is not expected to detract from the research objectives of state-wide trend discovery and is therefore accepted.

3.5 Assumptions and cautions assessment results

Aquacycle assumptions and cautions are received as either irrelevant, or accepted in the context of the research objectives. Having also accepted Aquacycle functions the next process is to calibrate and validate Aquacycle against published results.

3.6 Calibration and validation of Aquacycle

Usually calibration and validation are undertaken as separate but related processes. If the system uses a time series of recorded observations, then the first half of a time series is used to calibrate the system and the second half used to validate the calibrated system against these recorded observations. In this research the process is simplified to calibrating the system to reproduce results closely matching key research results. Therefore calibration will be defined as the process to refine Aquacycle parameter values to match the output of key research results and validation is the process of matching a second set of key research results using the calibrated parameters.

Calibration and validation of Aquacycle output is essential to demonstrate the general accuracy of results from this research. Ultimately, this research aims to determine rainwater tank hydrologic yield and water saving efficiency trends across Queensland, so it would be prudent to calibrate using key research papers that hold similar aims.

3.6.1 Calibration

The following three step process was undertaken to calibrate Aquacycle:

1. Adopt recommended calibrated parameter values included in Aquacycle user manual.

2. Adopt common parameter ranges from key research papers.
3. Compare Aquacycle output with key research results and adjust calibration parameters to increase the convergence between the two.

The recommended and adopted calibration parameters from the user manual are summarised in Table 3.2.

Table 3.2 Recommended and adopted Aquacycle calibration parameters

Function	**Parameter**	**Recommended**	**Adopted**
Stormwater	Percentage area of store 1 (%)	22	22
	Pervious store 1 capacity (mm)	32	32
	Pervious store 2 capacity (mm)	240	240
	Roof area initial loss (mm)	0	1
	Effective roof area (%)	100	100
	Base flow index	0.55	0
	Base flow recession constant	0.0025	0
	Rainwater tank first flush volume (L)	Not given	5
	Initial storage level (kL)	Not given	50%
Water use	Garden trigger-to-irrigate ratio	0.31	0.31

The roof area initial loss value of one was adopted against the manual recommendations as this value is common to many urban stormwater models. Base flow analysis is beyond the scope of research and so zero values will be used for the index and recession ratios. The first flush volume and initial storage level were identified as additional calibration parameters. These parameters could easily be used to scale down Aquacycle hydrologic yield and water saving efficiency predictions. As stated earlier there is a caution that Aquacycle may slightly over estimate rainwater tank hydrologic yield due to the daily time step. All other adopted calibration values are as recommended.

The second step involved defining other relevant input parameters to match Aquacycle as closely as possible to the key research parameters. Key researchers have been identified by the volumes of papers referencing their works and/or how relevant the simulation process used is to the research simulation process.

Dr P Coombes has extensive readership. It is difficult to find an article on this topic that excludes reference to Coombes. This is also ideal as the performance of PURRS, the second rated program in the simulation software performance criteria, can be compared with Aquacycle. The results from simulation in Brisbane (Coombes and Kuczera 2003) will be used to calibrate Aquacycle hydrologic yield estimation.

Jenkins (2007) attempts to discover water saving efficiency trends across the nation by applying a seasonality index domain. This is ideal to calibrate water saving efficiency estimation as Jenkins' work will be also be used as a benchmark for state-wide efficiency trends discovery.

By seeking a common parameter set between Coombes and Jenkins, then their relative performance can be included within the calibration process to increase convergence accuracy and reduce the number of calibration iterations needed. To seek a common parameter set a comparison of the parameter ranges engaged by each study is needed. These results including the adopted calibration parameters for Aquacycle are summaries in Table 3.3.

The rainwater tank volumes adopted are identical to Coombes and closely cover the lower half of volumes used by Jenkins. This provides a highly converged range of values. Adopting a 200 m^2 roof area is ideal as this value is common to both. The average annual consumption for three occupants in Brisbane including external irrigation adopted by Coombes is 689 L/d. Adopting 690 L/d also provides a close conversion with Jenkins 675 L/d being, hypothetical average household consumption for toilet flushing, bathroom, laundry and outdoor use.

Table 3.3 Parameter ranges from comparative studies and adopted values for calibration

Parameter	**Coombes**	**Jenkins**	**Taylor (calibration)**
Rainwater tank volumes (kL)	1, 2.5, 5, 7.5 & 10	1, 5, 10.5, 15 & 24	1, 2.5 5, 7.5 & 10
Roof Areas (m^2)	100, 150 & 200	200	200
Consumption (L/d)	1 – 5 occupants + outdoor irrigation	110, 257, 323, 433, 580, 675 and 734	Average daily consumption of 690
Time series rainfall data	100 years of 6 minute synthetic data ending 2002	113 years of daily BOM observations ending 2003	39 years daily BOM observations ending 2009

The discrepancies with time series data adopted are noteworthy. Coombes uses synthetically produced data. Jenkins uses daily recorded BOM data over a similar period to Coombes. The calibration data is also daily BOM records but more current and of less duration. A time series of over 39 years is considered suitable for inclusion of significant long term wetting and drying cycles such as the southern index and is not expected to skew the calibration process.

The first calibration pass showed that Aquacycle hydrologic yield and water saving efficiency predictions were approximately 10% higher then Coombes and Jenkins across the range of tank volumes. As stated earlier this overestimate to Coombes was anticipated due to time step limitations of Aquacycle. Adjustment was achieved by increasing the first flush volume to 120 L. Final calibration results are shown in Figure 4.1.

It should be noted that the daily irrigation demand variation over the simulation is being excluded from Aquacycle by adopting a fixed daily consumption of 690 L, as needed to conduct the calibration run. As recent external water usage studies are limited and Coombes' and Jenkins' research was undertaken pre water use education the irrigation demand function can only be reviewed for operation in accordance with the theory.

A study of the average monthly differential of actual evapotranspiration and precipitation for Brisbane over the simulation period would provide a good indication of the average monthly irrigation demand. The results are shown in Figure 4.2.

As new research on irrigation habits beyond water use education is available the accuracy of the irrigation demand section of Aquacycle should be reviewed.

3.6.2 Validation

The validation process was undertaken by adopting the daily consumption of 570 L/day and the final calibration parameter values. This closely matches Coombes' two bedroom house with outdoor water use (580 L/day) and Jenkins' hypothetical average house with toilet flushing, bathroom and outdoor use (560 L/day). The results are shown in Figure 4.3

3.7 Defining Aquacycle input parameters

The following input parameter files are used by Aquacycle and will be briefly explained:

- Climate data;
- Indoor water usage profile;
- Unit block;
- Cluster;
- Catchment;

- Measured parameters;
- Calibrated parameters; and
- Initial storage levels.

Before proceeding to explain these files, it is noteworthy to state how Aquacycle has been configured for this research. Aquacycle is configured with seven clusters, with each having one unit block. The only distinction between the unit blocks is the occupancy which ranges from one to seven for the respective one to seven clusters. This allows Aquacycle to conduct seven individual simulations in a single pass. The average annual data is taken from each of the seven cluster level output files, which is identical to running seven individual unit block simulations and taking the average annual unit block data. This process reduces the number of simulations needed by seven fold.

3.7.1 Climate data parameters file

The climate data used by Aquacycle must be imported using a comma separated values (CSV) file, but with the extension changed to '.clm'. See Figure B.1 in Appendix B for the Brisbane data file. The first line of this file contains three values being the start date, site name and end date of the simulation period. Dates are recorded using a numerical string where 1/1/1970 is recorded as 19700101. The global simulation period adopted and therefore climate data range is from 1/1/1970 to 18/06/2009. The remaining lines contain all observed BOM data as one daily record per line. These data lines have the formate of date, precipitation (mm) and potential evapotranspiration (mm). The form of evapotranspiration data taken from the BOM is FAO Penmam-Monteith (FAOPM).

In order to discover state-wide hydrologic yield and water saving efficiency trends much consideration was given to the locations of BOM data to include. Over site representation would result in redundant simulations and extended work for little return. Under site representation would detract from the accuracy of tend discovery.

Site selection would be necessary to represent the varying climates that exist within Queensland, therefore sites selection was based on climate classifications of Queensland.

Figure C.1 of Appendix C shows the BOM chart Seasonal Rainfall Zones of Australia chart. This chart was used to identify seven climate classes that exist within Queensland. Sites were selected as the main urban centre within each climate class. Table 3.4 shows the selected sites and climate classes.

Review of the spatial dispersion of these sites showed the central coast was poorly represented. It was therefore decided to include Rockhampton. A Queensland extract of the BOM chart showing the location of the key sites is shown in Figure 3.3.

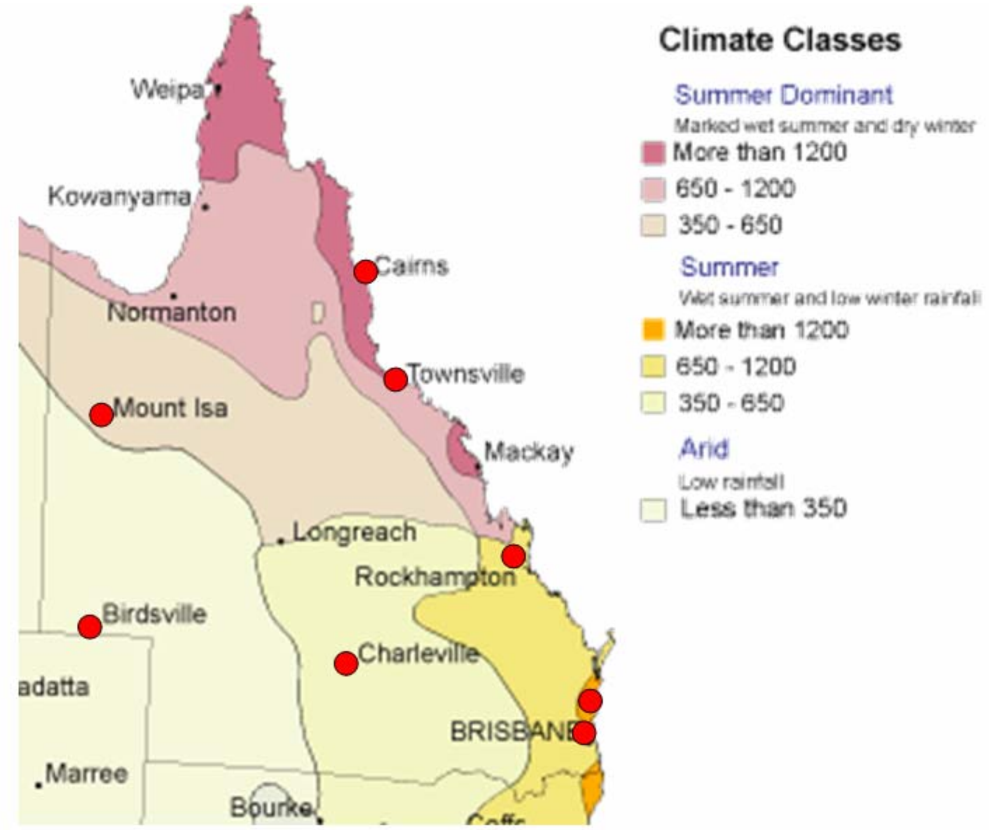

Figure 3.3 **Extract of the seasonal rainfall zones of Australia showing key sites**

Table 3.4 Key sites selected for BOM data and climate class

Key site	**Seasonality index (refer Section 3.9.3.2)**	**Average annual rain days**	**Climate class**
Birdsville	0.643	15	Arid – less than 350 mm median annual rainfall
Brisbane	0.322	90	Summer – 650 mm to 1200 mm median annual rainfall
Cairns	0.746	125	Summer Dominant – more than 1200 mm median annual rainfall
Caloundra	0.301	105	Summer – more that 1200 mm median annual rainfall
Charleville	0.427	35	Summer – 350 mm to 650 mm median annual rainfall
Mount Isa	0.851	25	Summer Dominant – 350 mm to 650 mm median annual rainfall
Townsville	0.487	75	Summer Dominant – 650 – 1200 mm median annual rainfall

The close proximity of Brisbane and Caloundra could not be avoided due to the climate class boundaries. Furthermore both of these locations have been considered for hydrologic yield studies that may be used for results comparison.

The inclusion of two sites within the ‘Summer – 650 mm to 1200 mm median annual rainfall’ climate class will be useful to determine the simulation difference across one select climate class which may identify possible enhancements on future sites selections.

As Data Drill time series data was supplied freely from USQ the longitude and latitudes of key sites were nominated to match patch point data locations. This would allow direct inclusion of actual recorded data from the BOM. The precipitation and evaporation data source was reviewed for all data to determine the extent of data sourced beyond daily interpolation. In all cases no data was from long term interpolation or synthetic pan evaporation. This is well within acceptable limits. An extract of BOM data obtained for Brisbane is shown in Figure C.2 of Appendix C.

3.7.2 Indoor water usage profile file

The indoor water usage data used by Aquacycle must be imported using a CSV file, but with the extension changed to '.wpf'. See Figure B.2 in Appendix B for the adopted indoor water usage profile. The first line of this file contains one string to identify the profile being loaded. The second to eighth lines contain the number of occupants from 1 to 7 and the respective daily house hold consumption split amongst kitchen, bathroom, toilet and laundry. The final line contains the hot water ratio used in the kitchen, bathroom and laundry.

Research has identified the affect of household occupancy on internal water usage, the usage split between kitchen, bathroom, toilet and laundry and the ratio of hot water use (Mitchell 2005). As this research was undertaken before water use education, the consumptions are excessive. This data was scaled down so the average household of 2.58 people (ABS 2004) using an current indoor consumption (post water use education) of 170 L/person/day (QWC 2009b). Refer to Table 3.5 for the adopted water usage profile.

3.7.3 Unit block parameter file

The unit block parameter file used by Aquacycle must be imported using a CSV file, but with the extension changed to '.ubl'. See Figures B.3 to B.7 in Appendix B for the 3 kL, 5 kL, 7.2 kL, 10 kL and 14.5 kL tank unit block parameter file, respectively. The first line of this file contains the number of clusters configured in Aquacycle.

This dictates the number of data lines to follow as each line contains the parameter values for each cluster. Table 3.6 details these parameters, the adopted values and justification. For parameter dimensions, which take a variety of values are varied to generate many unique simulations, the array of values is shown. A separate input file is needed for the number of values within each array.

Table 3.5 Aquacycle adopted water usage profile

Occupancy	Kitchen	Bathroom	Toilet	Laundry
1	24	75	68	39
2	38	122	112	71
3	49	166	147	124
4	56	196	180	155
5	60	216	201	178
6	72	245	226	204
7	84	273	252	229
Hot water ratio	0.6	0.5		0.25

Table 3.6 Unit block parameter values for the 3 kL tank simulations

Parameter	Value	Justification
Supply garden irrigation with imported water	No	By suppling only from the rainwater tank and allowing imported water to augment this supply then the rainwater tank deficit becomes the total augmented supply.
Rainwater tank storage capacity (m^3)	{2.4, 4, 6.1, 8.5, 12.3}	This is the operating capacity which varies for the rainwater tank volumes simulated. The capacity is less than the nominal capacity. Refer to Table 3.7.
Rainwater tank exposed surface (m^2)	0	This surface area is used to include direct precipitation and evaporation from the rainwater tank. As explained earlier the tanks are assumed to be enclosed to avoid

		evaporation loss and therefore not able to capture runoff from their roof area.
Rainwater tank first flush (L)	120	This value is the final calibration value refer Section 3.6.1
Hot water from rainwater tank	Yes	All demand is from rainwater tank for reasons explained for parameter 1.
Kitchen cold water from rainwater tank	Yes	All demand is from rainwater tank for reasons explained for parameter 1.
Bathroom cold from rainwater tank	Yes	All demand is from rainwater tank for reasons explained for parameter 1.
Laundry cold from rainwater tank	Yes	All demand is from rainwater tank for reasons explained for parameter 1.
Toilet water from rainwater tank	Yes	All demand is from rainwater tank for reasons explained for parameter 1.
Garden irrigation from rainwater tank	Yes	All demand is from rainwater tank for reasons explained for parameter 1.
Kitchen grey water for subsurface irrigation	No	Grey water usage is beyond the scope of this research.
Bathroom grey water for subsurface irrigation	No	Grey water usage is beyond the scope of this research.
Laundry grey water for subsurface irrigation	No	Grey water usage is beyond the research scope.
Wastewater storage capacity (m^3)	0	Wastewater modelling is beyond the research scope.
Wastewater exposed surface (m^2)	0	Wastewater modelling is beyond the research scope.
Treat kitchen wastewater	No	Wastewater modelling is beyond the research scope.
Treat bathroom wastewater	No	Wastewater modelling is beyond the research scope.
Treat laundry wastewater	No	Wastewater modelling is beyond the

		research scope.
Treat toilet wastewater	No	Wastewater modelling is beyond the research scope.
Garden irrigation from wastewater store	No	Wastewater modelling is beyond the research scope.
Wastewater overflow to sewer	No	Wastewater modelling is beyond the research scope.
Wastewater overflow to stormwater	No	Wastewater modelling is beyond the research scope.
Unit block runoff draining to cluster stormwater store	No	Cluster spatial scale analysis is beyond the research scope.
Supply toilet from a cluster stormwater store	No	Reticulated grey water is beyond the research scope.
Supply garden irrigation from a cluster stormwater store	No	Reticulated grey water is beyond the research scope.
Unit block wastewater draining to a cluster wastewater store	No	Wastewater analysis is beyond the research scope
Supply toilet from a cluster wastewater store	No	Reticulated grey water is beyond the research scope.
Supply garden irrigation from a cluster wastewater store	No	Reticulated grey water is beyond the research scope.
Supply toilet from a catchment stormwater store	No	Reticulated grey water is beyond the research scope.
Supply garden irrigation from a catchment stormwater store	No	Reticulated grey water is beyond the research scope.

Supply toilet from a catchment wastewater store	No	Reticulated grey water is beyond the research scope.
Supply garden irrigation from a catchment wastewater store	No	Reticulated grey water is beyond the research scope.

The operating volume of a rainwater tank is less than the nominal volume due to a loss of storage height. The hight lost adopted by this research is 300 mm. In accordance with similar studies (Coombes and Kuczera 2003) this height consists of three 100 mm layers being air gap to mains top up, operating height of mains float valve and an anaerobic base layer. The typical dimensions of the rainwater tanks uses are shown in Table 3.7.

Table 3.7 Dimensions of rainwater tanks included in research

Nominal volume (kL)	**Height (m)**	**Base area (m^2)**	**Operating volume (kL)**	**Description – All taken from National Poly Industries**
3	2.10	1.91	2.4	Slimline 3000
5	1.63	3.40	4	Medium 5000
7.2	2.32	3.70	6.1	Medium 7200
10	2.67	4.83	8.5	Large 10000 upright
14.5	2.40	7.50	12.3	Large 14500

3.7.4 Cluster parameter file

The cluster parameter file used by Aquacycle must be imported using a CSV file, but with the extension changed to ‘.clu’. Only one input file is needed for all simulations, refer Figure B.8 of Appendix B. The first line of this file contains the number of clusters configured in Aquacycle. This dictates the number of data lines to follow as each line contains the parameter values for each cluster. Table 3.8 details these parameters, the adopted values and justification.

Table 3.8 Cluster parameter values for all simulations

Parameter	**Value**	**Justification**
Stormwater storage capacity (m^3)	0	Cluster level analysis is beyond the research scope.
Stormwater exposed surface (m^2)	0	Cluster level analysis is beyond the research scope.
First flush volume (L)	0	Cluster level analysis is beyond the research scope.
Road runoff to stormwater store	No	Cluster level analysis is beyond the research scope.
Collect stormwater from upstream clusters	No	Cluster level analysis is beyond the research scope.
Wastewater storage capacity (m^3)	0	Wastewater analysis is beyond the research scope.
Wastewater exposed surface (m^2)	0	Wastewater analysis is beyond the research scope.
Collect wastewater from upstream clusters	No	Wastewater analysis is beyond the research scope.
Storage overflow to sewer	No	Wastewater analysis is beyond the research scope.
Storage overflow to stormwater	No	Wastewater analysis is beyond the research scope.
Aquifer storage capacity (m^3)	0	Aquifer analysis is beyond the research scope.
Aquifer maximum recharge rate (m^3/d)	0	Aquifer analysis is beyond the research scope.
Aquifer maximum recovery rate (m^3/d)	0	Aquifer analysis is beyond the research scope.

Public open space irrigation supplied from import water	No	Public open space is beyond the research scope.
Public open space irrigation supplied from cluster stormwater	No	Public open space is beyond the research scope.
Public open space irrigation supplied from cluster wastewater	No	Public open space is beyond the research scope.
Public open space irrigation supplied from catchment stormwater	No	Public open space is beyond the research scope.
Public open space irrigation supplied from catchment wastewater	No	Public open space is beyond the research scope.
Drain runoff into the cluster stormwater store	No	Public open space is beyond the research scope.

3.7.5 Catchment parameter file

The catchment parameter file used by Aquacycle must be imported using a CSV file, but with the extension changed to '.cmt'. Only one input file is needed for all simulations. Refer Figure B.9 of Appendix B. This file contains only one line of parameter values .The first line of this file contains the number of clusters configured in Aquacycle. Table 3.9 details these parameters, the adopted values and justification.

3.7.6 Measured and calibrated parameter and initial storage file

The measured and calibrated parameters and initial storage values used by Aquacycle must be imported using a CSV file, but with the extension changed to

‘.prm’ See Figures B.10 to B.18 of Appendix B for the various parameter and initial storage files used. The first line of this file contains the number of clusters configured in Aquacycle. This dictates the arrangement of the remaining data lines. Lines are grouped by measured parameters, calibrated parameters and initial storage values. The groups are separated by a line with a single zero. The number of data lines in each group is the number of clusters configured. Each line contains the parameter group values for each cluster. Table 3.10 to 3.12 details these parameters, the adopted values and justification.

Table 3.9 Catchment parameter values for all simulations

Parameter	**Value**	**Justification**
Catchment area (ha)	0.63	This is the sum of seven unit block of 900 m^2 each.
Stormwater storage capacity (m^3)	0	Catchment level analysis is beyond the research scope.
Stormwater exposed surface (m^2)	0	Catchment level analysis is beyond the research scope.
First flush volume (L)	0	Catchment level analysis is beyond the research scope.
wastewater storage capacity (m^3)	0	Catchment level analysis is beyond the research scope.
wastewater exposed surface (m^2)	0	Catchment level analysis is beyond the research scope.
Wastewater storage overflow to stormwater not sewer	No	Wastewater analysis is beyond the research scope.

Table 3.10 Measures parameter values for the 25% effective roof area and 50% irrigated garden area simulations

Parameter	**Value**	**Justification**
Number of blocks	1	This is the number of unit blocks within each cluster
Average occupancy	{1, 2, 3, 4, 5, 6, 7}	As previously discussed the occupancy range is configured in this way to reduce simulation time. Note that separate input files are not needed for this range as individual cluster data is listed in the input file.
Area of unit block (m^2)	900	Refer to Figure 3.4.
Area of garden (m^2)	500	Refer to Figure 3.4.
Area of roof (m^2)	300	Refer to Figure 3.4.
Area of pavement (m^2)	900	Refer to Figure 3.4.
Percent of garden irrigated	{0, 25, 50}	A limited range is provided here. Zero is included to allow independent analysis on the internal water demands.
Total area of cluster (ha)	0.09	This is the same as the unit block.
Cluster road area (ha)	0	Cluster scale analysis is beyond the research scope.
Area of public open space (ha)	0	Public open space is beyond the research scope.
Percent of public open space irrigated	0	Public open space is beyond the research scope.
Leakage rate %	0	Reticulation leakage rate is beyond the research scope.
Stormwater output flows into cluster number	0	Cluster scale analysis is beyond the research scope
Wastewater output flows into cluster number	0	Cluster scale analysis is beyond the research scope

Table 3.11 Calibrated parameter values for the 25% effective roof area and 50% irrigated garden area simulations

Parameter	Value	Justification
% area of pervious store 1	22	Refer calibration, Section 3.6.1.
Capacity of pervious store 1 (mm)	32	Refer calibration, Section 3.6.1.
Capacity of pervious store 2 (mm)	240	Refer calibration, Section 3.6.1.
Roof area maximum initial loss (mm)	1	Refer calibration, Section 3.6.1.
Effective roof area (%)	{25, 50, 75}	These effective roof areas represent single, dual and greater number of connections to the rainwater tank or small medium and large dwellings.
Road area maximum initial loss (mm)	0	Cluster scale analysis is beyond the research scope.
Effective road area (%)	0	Cluster scale analysis is beyond the research scope.
Base flow index ratio	0	Base flow is beyond the research scope
Base flow recession constant ration	0	Base flow is beyond the research scope
Wastewater infiltration index ratio	0	Wastewater analysis is beyond the research scope.
Wastewater infiltration recession constant ratio	0	Wastewater analysis is beyond the research scope.
Percent of surface area as wastewater inflow	0	Wastewater analysis is beyond the research scope.
Garden trigger-to-irrigate ratio	0.31	Refer calibration, Section 3.6.1.
Public open space	0	Public open space analysis is beyond the

trigger-to-irrigate ratio		research scope.

Table 3.12 Initial storage values for the 25% effective roof area and 50% irrigated garden area simulations

Parameter	Value	Justification
Rainwater tank storage level (m^3)	2	Refer calibration, Section 3.6.1.
Treated wastewater storage level (m^3)	0	Wastewater analysis is beyond the research scope.
Cluster stormwater storage level (m^3)	0	Cluster scale analysis is beyond the research scope.
Cluster treated wastewater storage level (m^3)	0	Cluster scale analysis is beyond the research scope.
Aquifer storage level (m^3)	0	Aquifer analysis is beyond the research scope.

By adopting these input parameters the typical unit block can now be defined

3.8 Establish a typical unit block configuration

Figure 3.4 shows the typical unit block configuration adopted with all Aquacycle simulations.

3.8.1 Typical allotment area

A 900 m^2 allotment was chosen as this is the approximate median area of allotments considered in this research. Townhouse allotments can be as small as 100 m^2 and rural residential blocks can be many acres. The actual area of the unit block is not a significant factor. More significant is the irrigated garden area and effective roof area.

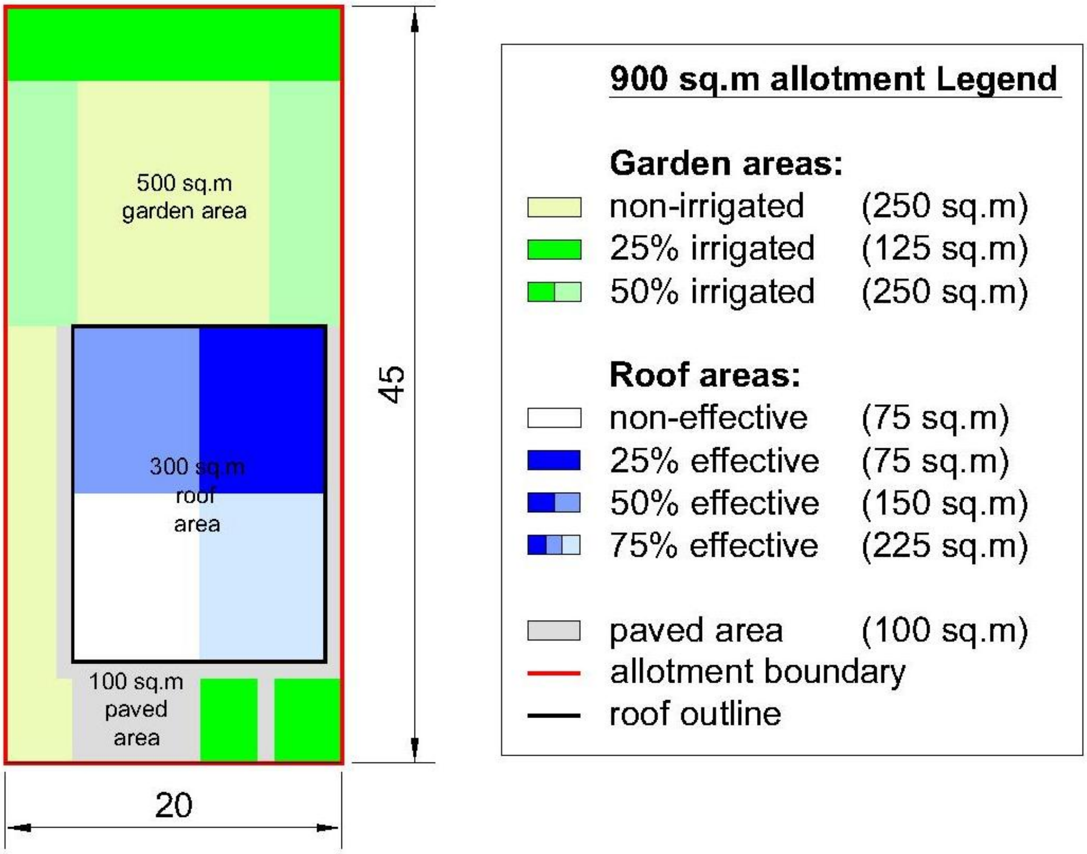

Figure 3.4 **Typical unit block configuration**

3.8.2 Typical irrigated garden area

The irrigated garden areas chosen of 125 m^2 and 250 m^2 represent the practical lower and upper limits, respectively, of irrigation areas when considering water use education. As stated earlier little research is available on external irrigation habits prior to this education so these are judgment values.

3.8.3 Typical effective roof area

The effective roof areas were chosen as they represent two scales. The first scale is single, dual or more connection(s) to a rainwater tank. The second scale is the maximum effective area available for a townhouse, medium house or larger family home. Adopting these scales allows for many combinations. For example, the 50% effective roof area (150 m^2) could represent two rainwater tank connections on a large family home or the practical maximum on a medium size house.

3.8.4 Typical paved area

The paved area of 100 m^2 would represent a driveway and paths surrounding the front and sides of the dwelling. As previously stated, this area is considered to not contribute to stormwater flows within the unit block as direct stormwater discharge to the roadway or subsurface drainage system is assumed.

This completes the preparation needed before undertaking the research simulations. The magnitude of the five parameters dimensions are summarised as eight sites, five rainwater tank volumes, three effective roof areas, three garden irrigation areas and seven occupancies This creates a massive 2520 unique situations that were individually simulated Aquacycle.

3.9 Trend discovery

The procedure adopted to undertake the state-wide hydrologic yield and water saving efficiency trend discovery phase was:

- Identify graphing and regression programs suitable for handling large data sets;
- Concatenate output data;
- Reproduce key research benchmarks; and
- Consider an alternate method for site indexation.

3.9.1 Graphing and regression program identification.

Microsoft Excel 2003 is well-regarded for quality graphs and many forms of regression. Previous engineering work with Excel had shown the capabilities of data sets size would not be breached with this research. Excel was therefore adopted to perform graphing and regression.

Before Excel could be used the 2520 individual output text files were concatenated into a single master spreadsheet.

3.9.2 Concatenating output data

MathWorks Matlab 7.1.0.124 was used to concatenate the output data. A simple script files was created which extracted the average annual summary line from each nominated data file and created an Excel file of the concatenated results. A simple interface was included in the scrip which allowed for selection of any one or all of the values within each parameter dimension. This allowed all simulations or a sub group of simulations to be concatenated as needed. See Figure D.1 in Appendix D for concat.m code. From this point, key research benchmarks were reproduced using current BOM data.

3.9.3 Reproduction of key research benchmarks

As discussed in the literature review there are many studies that attempt to determine hydrologic yield trends between sites. The accuracy of these results can be improved which provides the scope for this research. The first step to building on from existing knowledge is to reproduce this work using the latest BOM data. The two research benchmarks to be reproduced are hydrologic yield estimation from average annual precipitation and water saving efficiency from seasonality index.

The works of Coombes and Jenkins will be reproduced to create benchmarks and to maintain familiarity from the calibration process.

3.9.3.1 Hydrologic yield estimation benchmark

Hydrologic yield is widely determined from many precipitation statistics, with the most common being average annual precipitation. Figure 4.4 shows the average annual hydrologic yield derived from average annual precipitation for the same series of unit block configurations simulated at each site. This benchmark is founded by key research (Coombes 2003).

3.9.3.2 Efficiency benchmark

The best results for efficiency trends are presented by Jenkins (2007) and are dependant on a seasonality index. The seasonality index (SI) is determined by the equation:

$$SI = \frac{1}{\overline{R}} \sum_{j=1}^{12} \left| X_j - \frac{\overline{R}}{12} \right| \tag{3.16}$$

Given that SI is dependant on the time series data used, new values have been determined from the BOM data used in this research. Refer to Table 3.13 for the comparison between Jenkins' and Taylor's SI values. It should be noted that due to Jenkins conducting national scale research, the resolution of Queensland SI values is limited. The revised SI values were calculated using Matlab. See Figure D.2 in Appendix D for SI.m code.

Figure 4.5 shows the water saving efficiency derived from SI for the same series of unit block configuration simulated for the hydrologic yield benchmark.

Table 3.13 SI values for key sites

Site	Jenkins' SI	Taylor's SI	Relative error
Birdsville	-	0.643	-
Brisbane	0.363	0.322	11.4%
Cairns	0.765	0.746	2.5%
Caloundra	-	0.301	-
Charleville	-	0.427	-
Mount Isa	-	0.851	-
Rockhampton	-	0.487	-
Townsville	0.841	0.789	6.2%

From Table 3.13 a good SI correlation between Jenkins and Taylor can be seen.

3.9.4 Alternate form of site indexation (Taylor's Hyetology Index)

An alternate form of site performance indexation was determined based on rainwater tank mass balance failure principles. There are two modes of failure within the simulation. Either the rainwater tank runs dry from a period of consecutive days of low or no precipitation or there is excessive spillage loss from a day or period of days with excessive precipitation. A measure of the ratio of failure days to simulation days determined for each site is the basis of Taylor's Hyetology Index (THI).

As THI is new research it will be explained in full. THI is defined by the equation:

$$THI = \frac{\left(D_{dry} + C_{150}.D_{150}\right)}{D_{total}} V_f - C_t.V_t \tag{3.17}$$

Where:

D_{dry}	is the first quantity of failure being the number of nil daily precipitations in the time series for each site.
D_{150}	is the second quantity of failure being the number of daily excessive precipitations in the time series for each site. The excessive daily precipitation threshold of 150 mm was adopted by trialling thresholds above the highest daily precipitation for Birdsville, the climate where excessive precipitation is least dominant. Birdsville’s maximum daily precipitation observation was 129 mm. This process allowed site excessive failure to be quantified relative to Birdsville’s base of nil excessive failure.
D_{total}	is the number of daily observations in the time series for each site. This is constant for all sites and takes the value 14414.
V_f	is the nominal rainwater tank volume (kL) that fails by overflowing under the excessive precipitation failure mode and takes the value of 12.5 kL. This failure volume is defined by daily precipitation exceeding 150 mm on an effective roof area of at least 75 m^2 (the smallest area included in this research). It should be noted that operating volume that fails is 11.3 kL, ($0.15\ m \times 75\ m^2$). Justification on using nominal rainwater tank volumes follows.
C_{150}	is the excessive rainfall coefficient and takes the value 34.0. This coefficient is needed to account for the under representation of excessive rainfall days in the time series relative to the heightened significance of this failure mode. This is best qualified by an example.

Rockhampton recorded the highest daily precipitation of 532 mm. In the best case scenario, rainwater tanks are empty and the first approximate 150 mm fills the tank. The remaining approximate 380 mm is lost from the system. This loss compared to average annual precipitation is twice Birdsville's and almost half Rockhampton's. A reduction of average annual precipitation of this magnitude is likened to relocating Rockhampton to Mount Isa where the quantity of failure days $\left(D_{dry} + D_{150}\right)$ is 23% higher. Note that this is considering only one of the eight excessive failure events discovered for Rockhampton.

The value of 34.0 was determined using Matlab trial and error regression.

C_t is the rainwater tank volume regression coefficient and takes the value 0.12. THI has the units of kL. This allows the rainwater tank volume parameter dimension to be considered when calculating the index. The affect is rainwater tank volume is no longer dependent in hydrologic yield and water saving efficiency determination.

The value of 0.12 was determined using Matlab trial and error regression.

V_T is the nominal rainwater tank volume (kL) which takes the array {3, 5, 7.2, 10, 14.5}. As stated above, this allows for removal of rainwater tank dependence in hydrologic yield and water saving efficiency determination.

Table 3.14 shows the THI values by site and nominal rainwater tank volume used to generate research results. The values were calculated using Matlab. See Figure D.3 in Appendix D for THI.m code.

Table 3.14 Taylor’s Hyetology Indexes used for regression

Site	D_{dry} (days)	D_{150} (days)	Taylor’s Hyetology Index (THI) (kL) by nominal rainwater tank volume (kL)				
			3	5	7.2	10	14.5
Birdsville	13188	0	11.08	10.84	10.57	10.24	9.70
Brisbane	9052	7	7.70	7.46	7.19	6.86	6.32
Cairns	7129	52	7.36	7.12	6.85	6.52	5.98
Caloundra	8146	14	7.12	6.88	6.61	6.28	5.74
Charleville	11484	0	9.60	9.36	9.10	8.76	8.22
Mount Isa	12026	1	10.10	9.86	9.59	9.26	8.72
Rockhampton	9749	8	8.33	8.09	7.83	7.49	6.95
Townsville	10043	23	9.03	8.79	8.52	8.19	7.65

Refer to Table E.1 of Appendix E for a full list of THI values calculated for additional sites throughout Queensland.

The use of nominal rainwater tank volumes to determine THI is intended to aid the application of this research. It was considered more appropriated to simply lookup the total volume from Table 3.14 or Table E.1 in Appendix E rather then expecting the end user to calculate the rainwater tank operating volume.

3.10 Summary

From a short list of programs Aquacycle rated the highest relevant to the research objectives. Aquacycle functions, assumptions and cautions were reviewed and found to be ideal for use as a rainwater tank mass balance simulation program. Aquacycle was calibrated and validated against key research results with high convergence. This provides high confidence in the quality and validity of simulation results performed by this research.

The Taylor’s Hyetology Index has been created from the fundamental modes of failure inherent to the operation of a rainwater tank. This new form of indexation has an increased capacity to remove dependence on parameter dimensions including location and rainwater tank volume. The index has been designed with wider adaptation in mind to increase the scope of engagement beyond state wide investigations.

Chapter 4

Results

4.1 Calibration

Figure 4.1 shows the final calibration run fitted to Coombes and Jenkins when adopting a 120 L first flush volume and 2 kL initial storage volume. An excellent convergence between Aquacycle and Coombes over the rainwater tank volume range 3 kL to 10 kL can be observed. In this region the maximum relative error is 3% and average is 1%. The minimum rainwater tank volume adopted for the trend discovery phase is 3 kL; therefore, this is considered an excellent calibration result.

The maximum relative error of Aquacycle over Jenkins using the rainwater tank range of 3 kL to 10 kL is 7% and the average is 5%. Aquacycle slight over prediction could be accountable to Jenkins’ daily consumption rate being 2% less. Higher consumption gives higher storage availability and inturn higher average annual hydrologic yield. This calibration result is therefore very good.

Noting that the differential axis is in reverse order, Figure 4.2 shows the irrigation demand closely mirrors the precipitation and actual evapotranspiration differential. The peak water usage period is centred on September. This suggests the irrigation demand function is functioning correctly and the external water usage within Aquacycle is suitably calibrated.

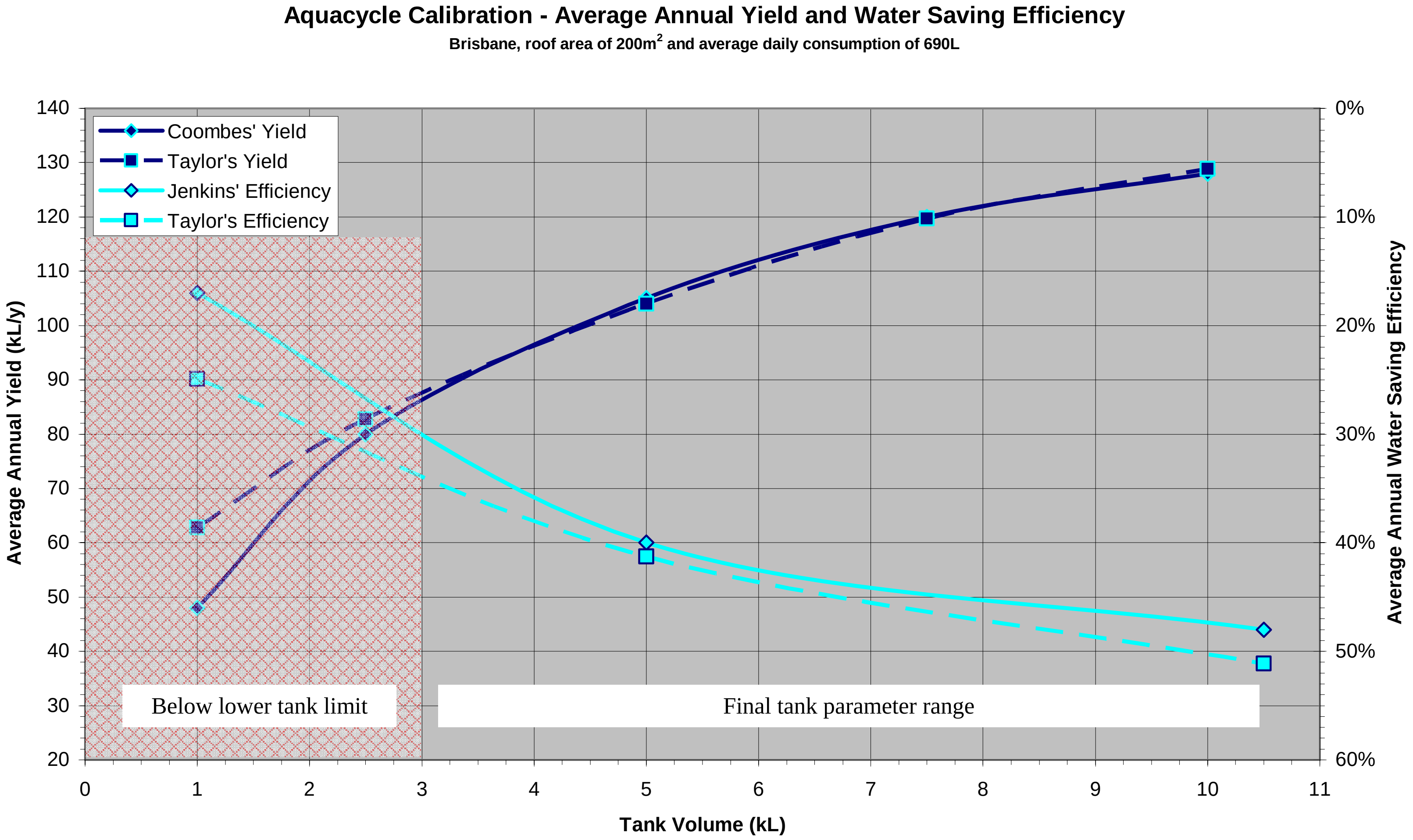

Figure 4.1 Aquacycle final calibration run (Taylor) fitted to Coombes and Jenkins

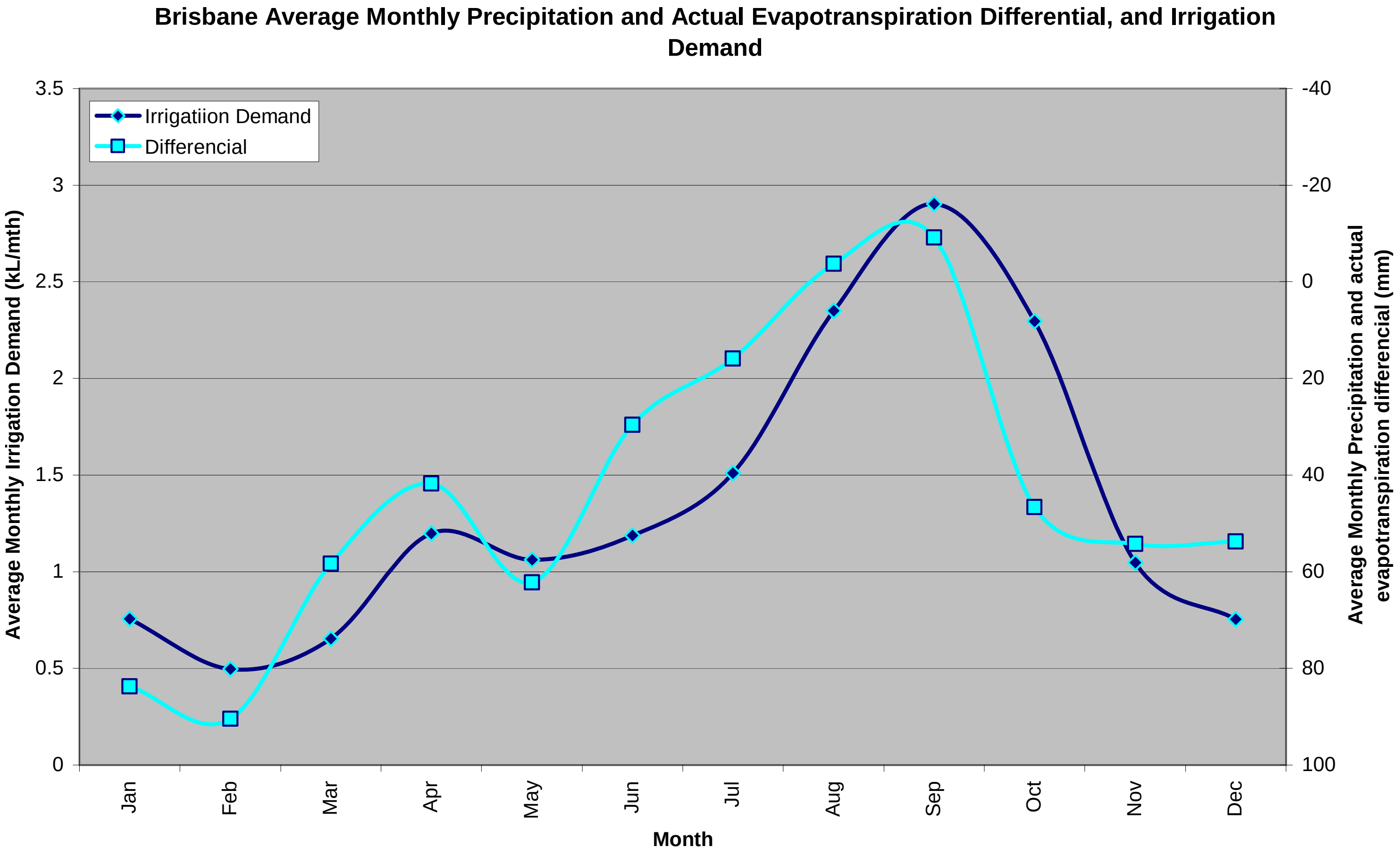

Figure 4.2 **Aquacycle irrigation demand compared to average monthly actual evapotranspiration and precipitation differential**

4.2 Validation

Figure 4.3 shows the convergence with Coombes remains excellent with the average relative error remaining at 1%. The convergence with Jenkins is weakened by the average relative error increasing to 13%. Some of the correlation error with Jenkins is accountable to the 2% relative increased consumption used by Aquacycle. This result shows that the convergence between Coombes and Jenkins is not as consistent as first thought, but still very good.

Validation convergence is typically slightly weaker than calibration. As a slight divergence between Coombes and Jenkins has been discovered, this validation result is still considered very good.

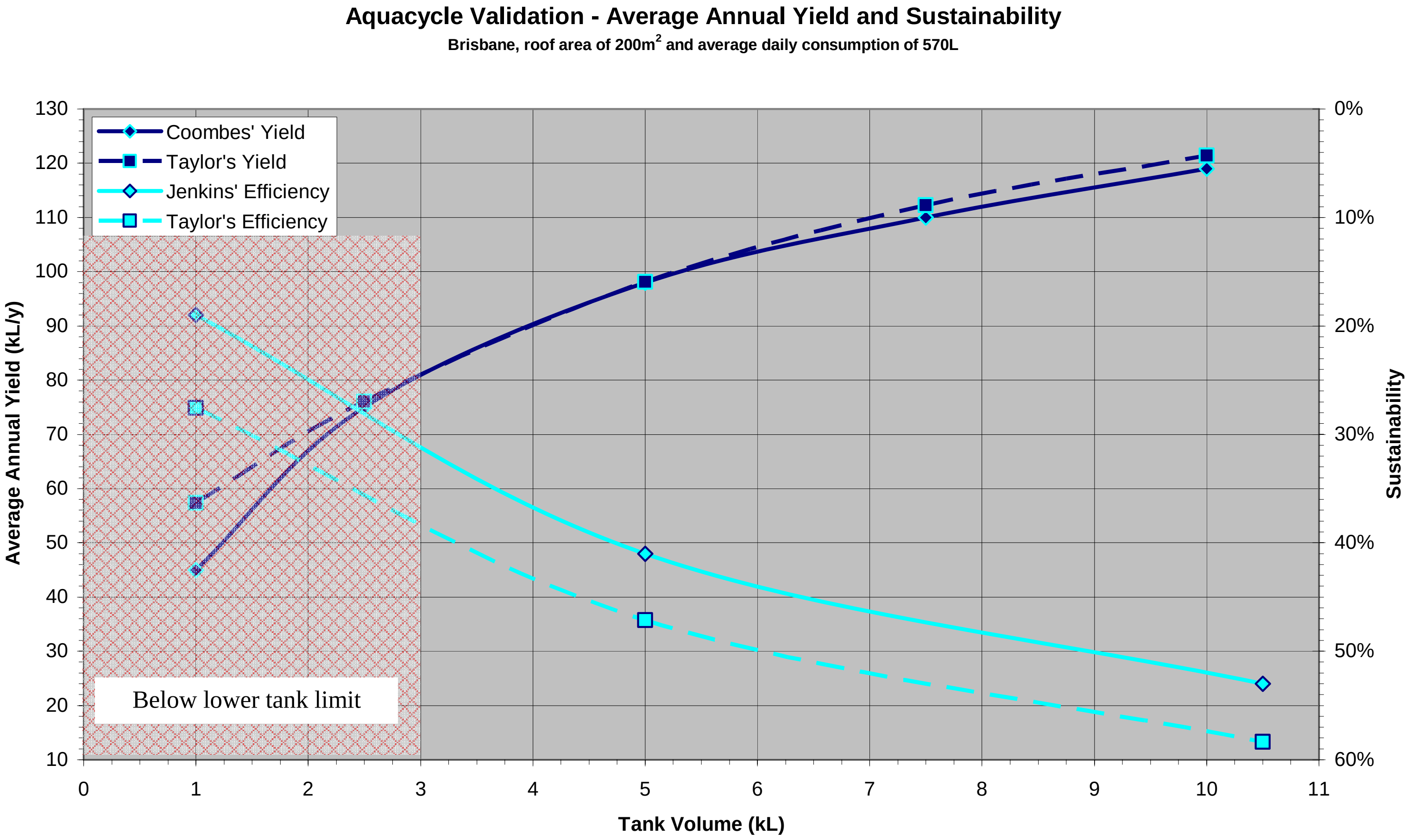

Figure 4.3 **Aquacycle validation run (Taylor) fitted to Coombes and Jenkins**

4.3 Hydrologic yield benchmark

Figure 4.4 shows an approximate average regression of ($r^2 = 0.90$), but confidence is not entirely assured. A maximum or asymptote is likely immediately beyond the upper domain. This has high potential to skew the upper polynomial regression. This is best qualified with an example. If the range of values was further restricted by removing the three highest average annual precipitations then a turning point would have been identified at approximately 1000 mm. This demonstrates that hydrologic yield results taken from the upper domain (1500 mm and above) would have lower regression confidence.

Furthermore, as a maximum or asymptote is being found this demonstrates a linear relationship between average annual precipitation and average annual yield, as adopted by (enHealth 2004) and (MJA 2007) would provide a poor result.

There is another limit with Figure 4.4. Considering there are three parameter dimensions in use, the product of there magnitudes equals the number of charts needed to report all 2520 simulations, this being 45 charts. Producing this series of charts would be beyond the research objects of providing a straightforward solution. This identifies areas of improvement over the benchmark as increasing regression confidence and reducing the number of charts needed in the series to report all simulations.

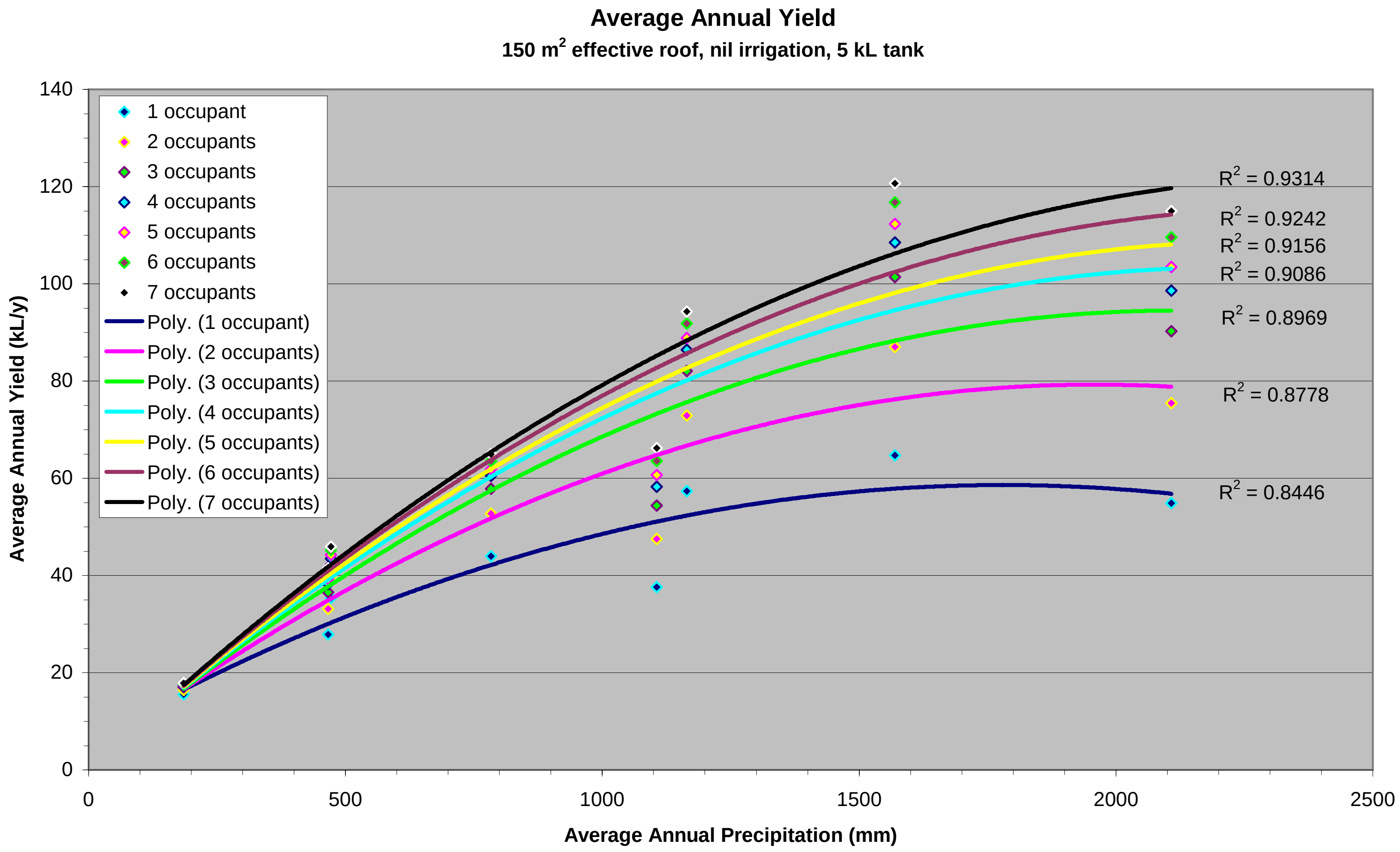

Figure 4.4 Average annual hydrologic yield derived from average annual precipitation and occupancy using polynomial regression

4.4 Water saving efficiency benchmark

From Figure 4.5 it can be seen that the accuracy of SI to predict water saving efficiency within Queensland is very limited. This is despite Jenkins' report of good national regression ($r^2 = 0.78$). The regression loss observed here is likely due to Jenkins' national site representation overpowering the state trend and the changes to SI values through using current BOM data. This aside, SI is unitless so opportunity to remove dependence from the ranging parameters exists, but is likely to be difficult.

This suggests that SI is flawed for Queensland state-wide trend discovery.

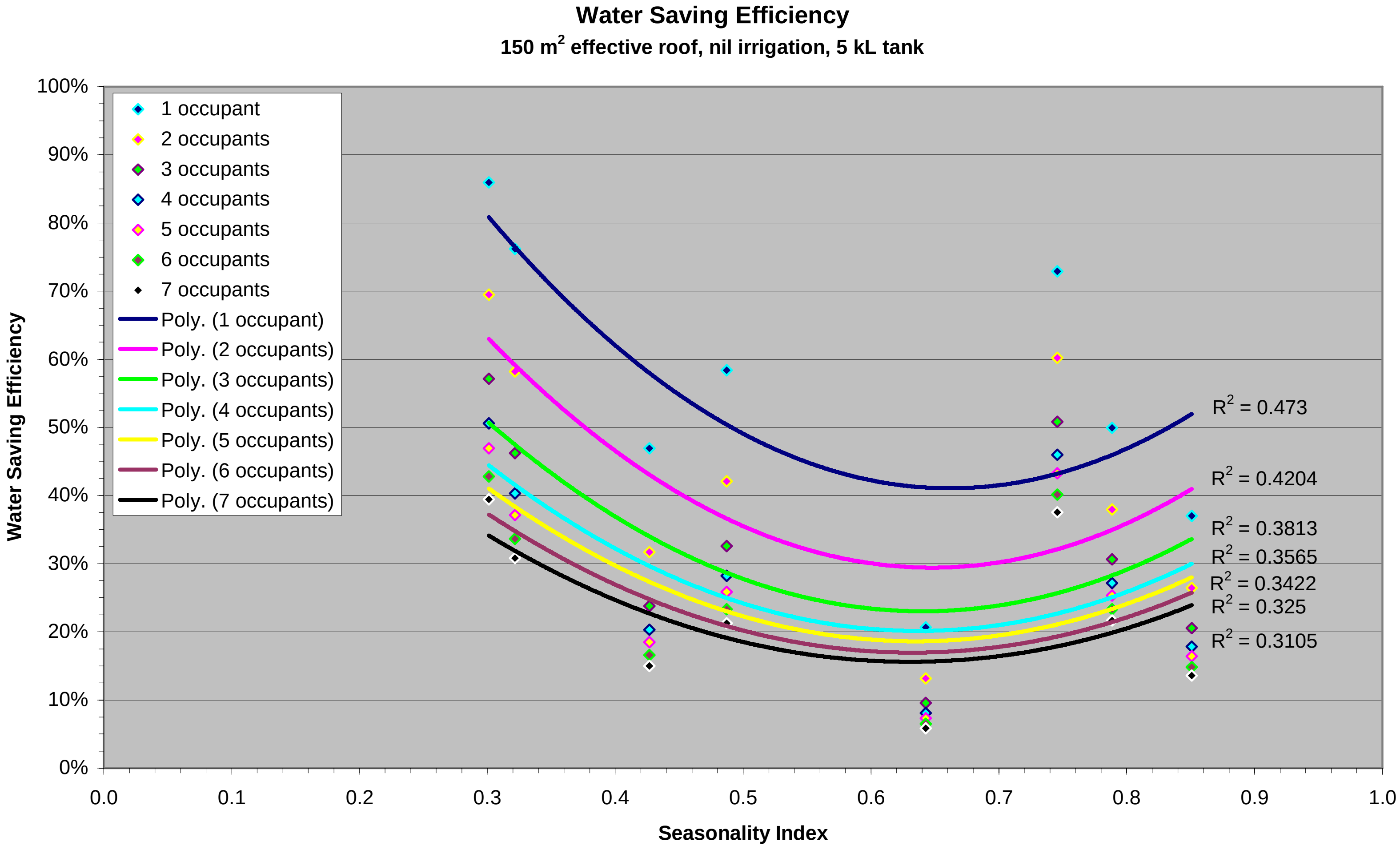

Figure 4.5 **Water saving efficiency derived from seasonality index and occupancy using polynomial regression**

4.5 Hydrologic yield detailed regression

From Figure 4.6 an average polynomial regression of $r^2 = 0.95$ can be seen. This is an increase from the benchmark of 0.90. Also the magnitude of data points used for each regression has increased by a factor of five, due to the inclusion of both site and tank volume parameter dimensions. This represents the combination of five rainwater tank volumes simulated at all sites.

The polynomial regression curve is contained within upper and lower domain limits which are both tending to linear. This gives a thorough definition of the curve and provides regression confidence throughout the domain unlike the benchmark, where confidence about the upper domain was reduced.

See Figures F.1 to F.9 in Appendix F for the complete series of hydraulic yield detailed regression charts.

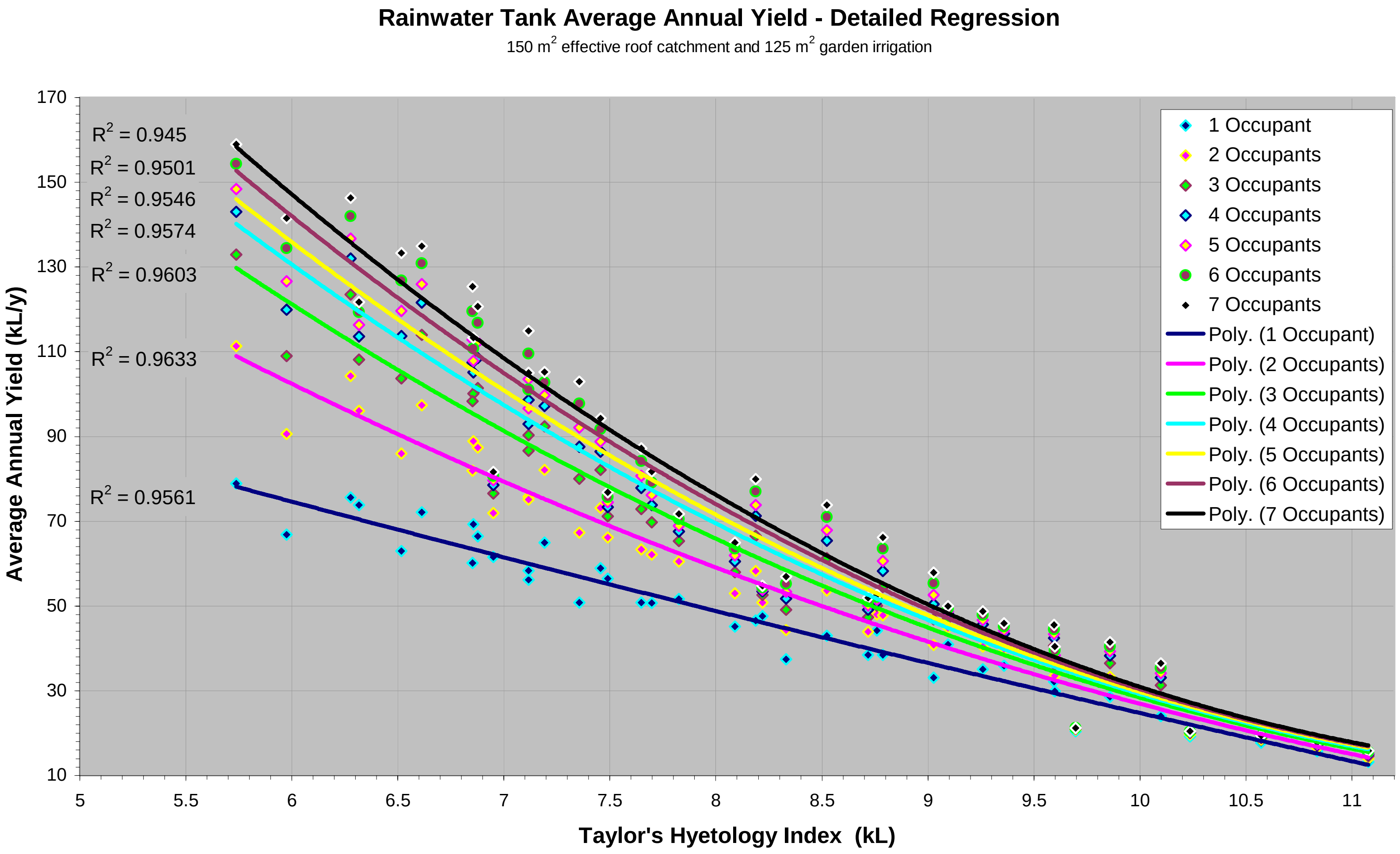

Figure 4.6 **Hydrologic yield estimate from THI and occupancy using polynomial regression**

4.6 Water saving efficiency detailed regression

From Figure 4.7 an average exponential regression of $r^2 = 0.92$ can be seen. This is a substantial increase from the benchmark of 0.36. Also it should be noted that the magnitude of data points used has increased by a factor of five. This represents the combination of five rainwater tank volumes simulated at all sites.

The exponential regression curve shows reduced confidence in the lower domain. Further convergence here would be a recommendation for future work

See Figures F.10 to F.18 in Appendix F for the complete series of charts.

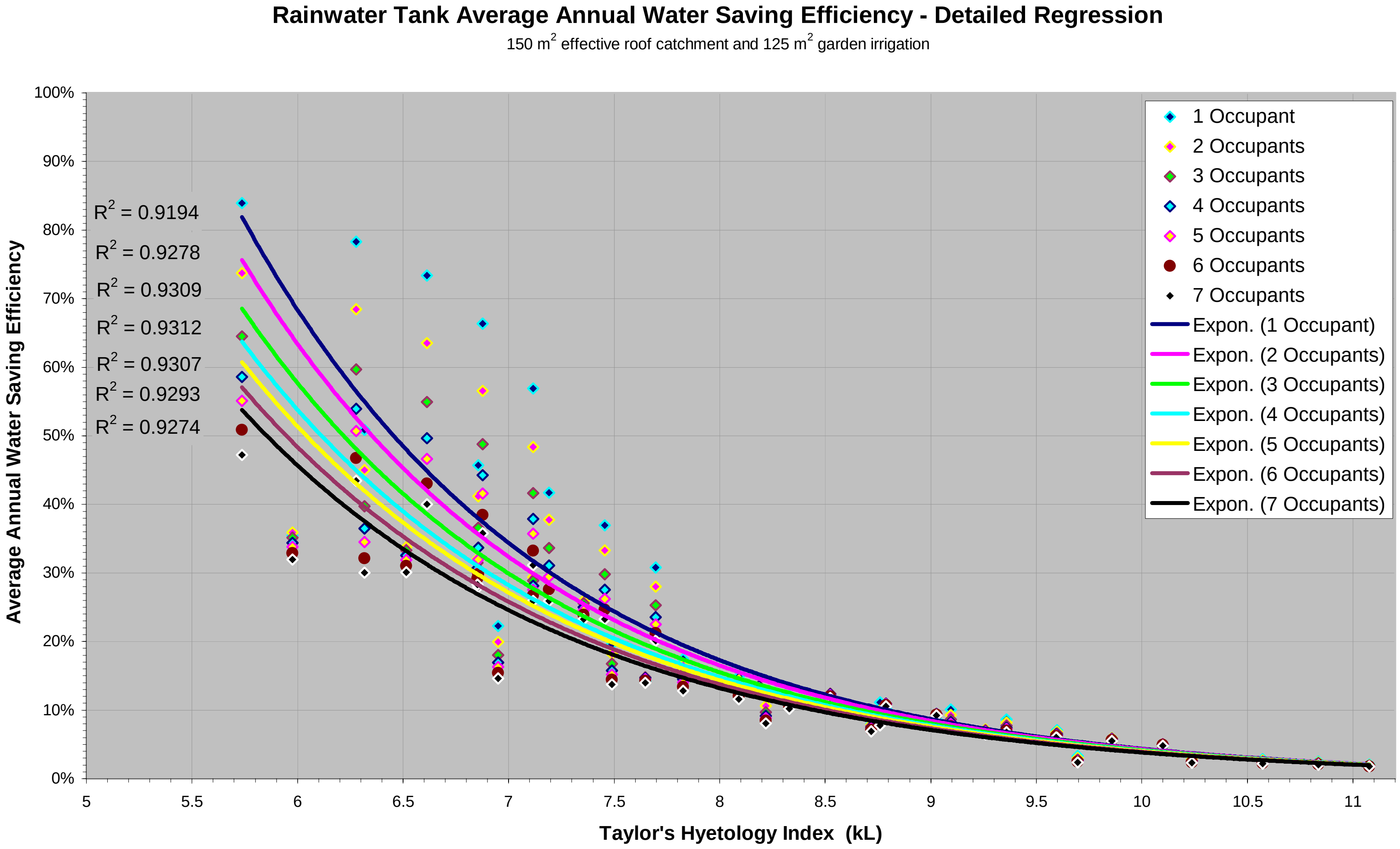

Figure 4.7 **Water saving efficiency estimate from THI and occupancy using exponential regression**

4.7 Combined hydrologic yield and water saving efficiency – Generic tank selection charts

As THI forms a common domain for hydrologic yield and water saving efficiency the two calculations can be combined on a single chart. This reduces the number of charts typically used to represent Queensland by a factor of 10.

The combined charts together with Table E.1 in Appendix E provide a comprehensive tank selection tool.

These charts can be easily simplified to represent one location by reducing the domain of THI values to those reported in table E.1 of Appendix E, for the chosen site. In addition the tank volumes could be overlayed on the domain to negate the need for the THI table altogether.

The process of determining hydraulic yield and water saving efficiency from THI selection charts follows the process:

- Determine THI for specific site and tank volume from Table E.1 in Appendix E. Note that linear interpolation and limited linear extrapolation can be used over the tank volume dimension; however, this is considered beyond the homeowner or developers typical ability.
- Locate the tanks selection chat that matches the effective roof area and irrigation requirements for the development.
- Read the hydraulic yield and water saving efficiency from this chart using the yield and efficiency occupancy curves and the THI value.

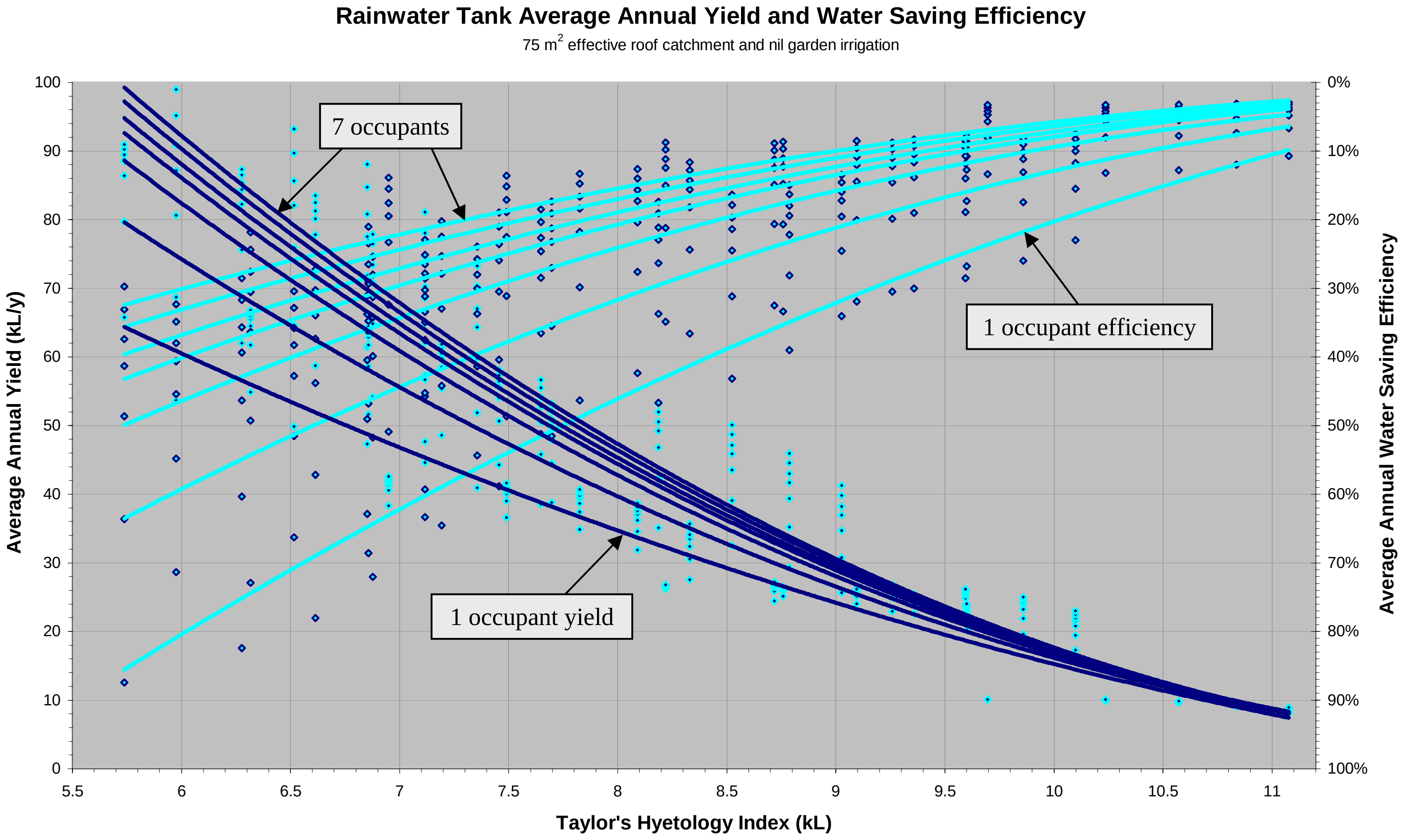

Figure 4.8 Hydrologic yield and water saving efficiency for 75 m^2 effective roof area and nil garden irrigation derived from THI and occupancy using polynomial regression

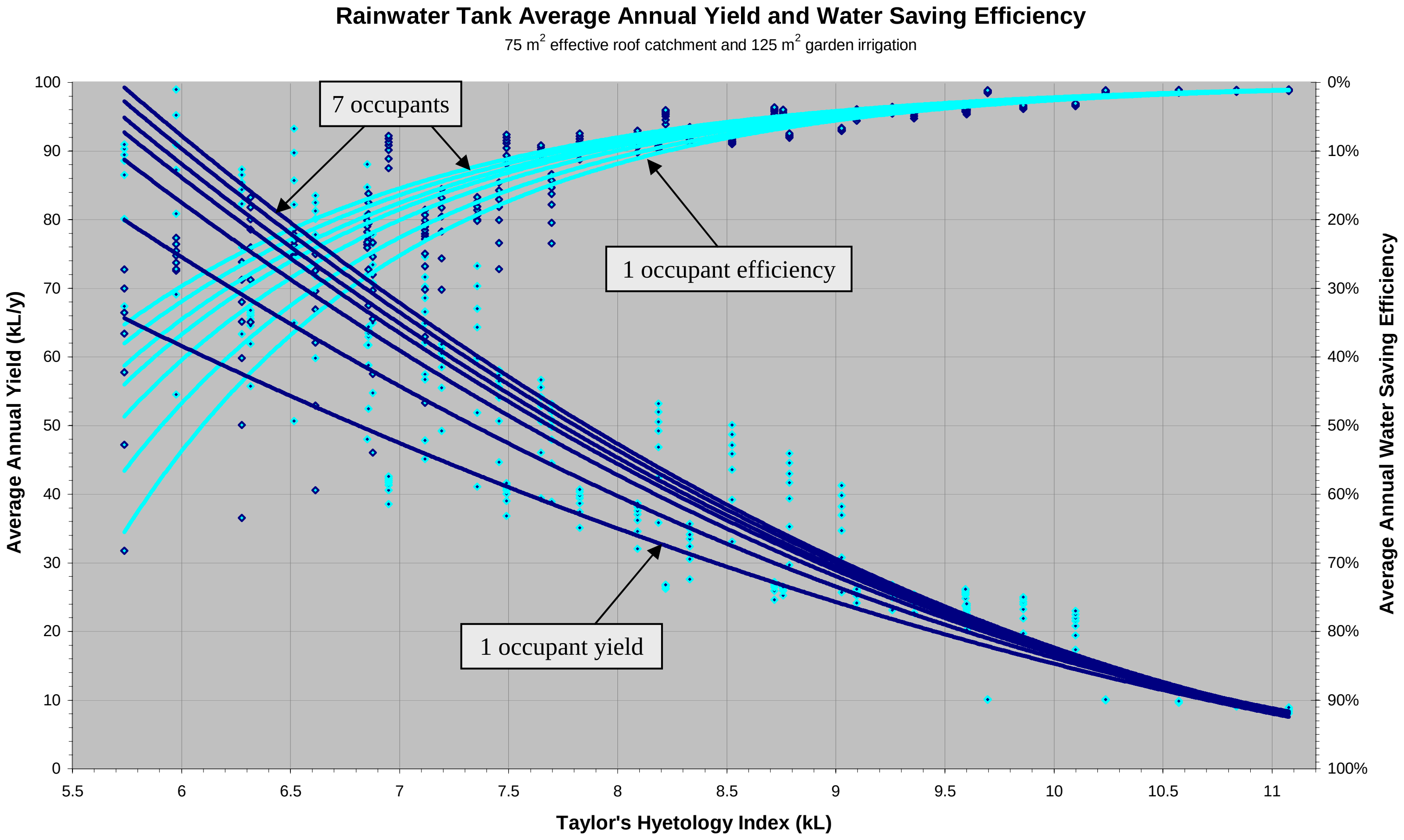

Figure 4.9 Hydrologic yield and water saving efficiency for 75 m^2 effective roof area and 125 m^2 garden irrigation derived from THI and occupancy using polynomial and exponential regression, respectively

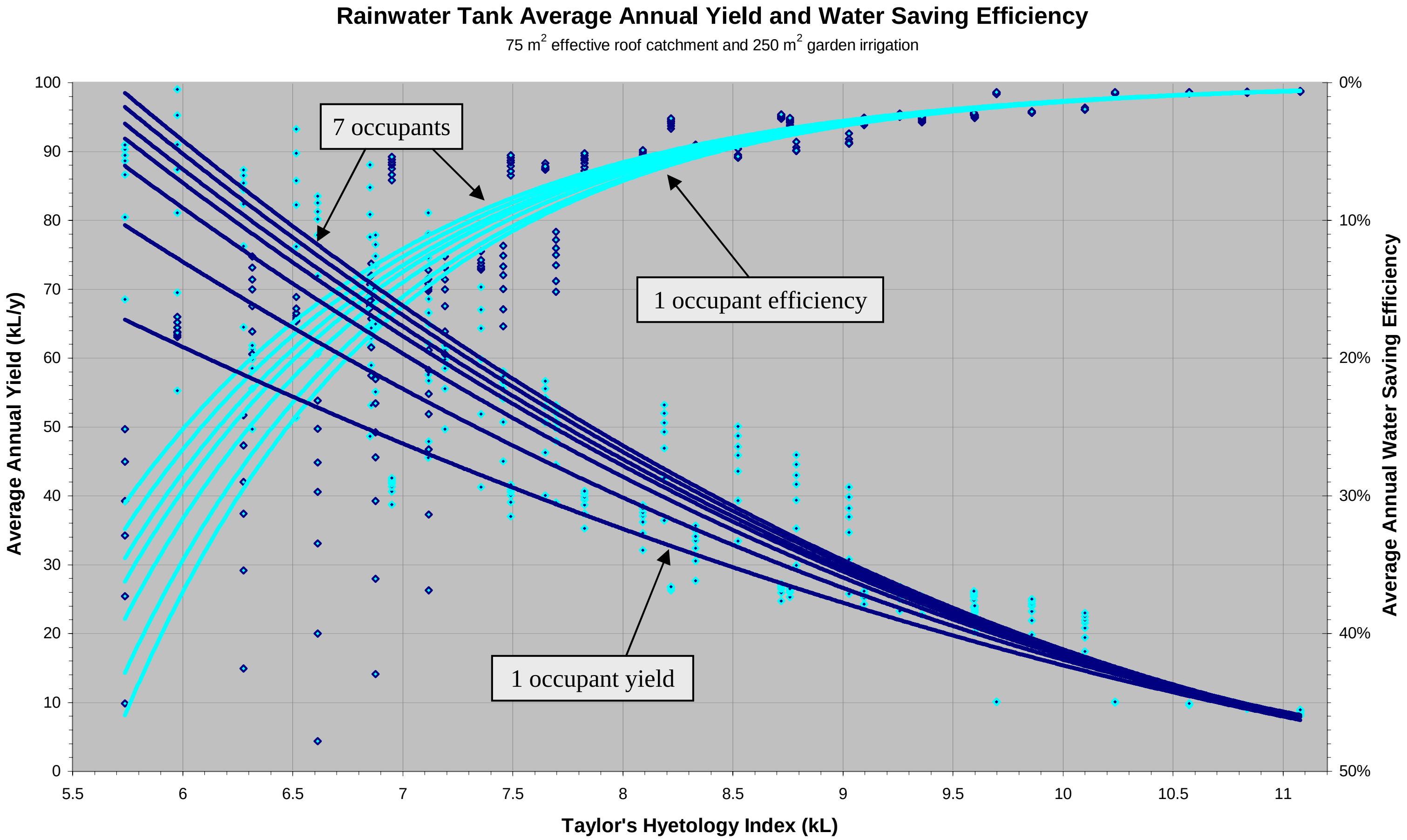

Figure 4.10 **Hydrologic yield and water saving efficiency for 75 m^2 effective roof area and 250 m^2 garden irrigation derived from THI and occupancy using polynomial and exponential regression, respectively**

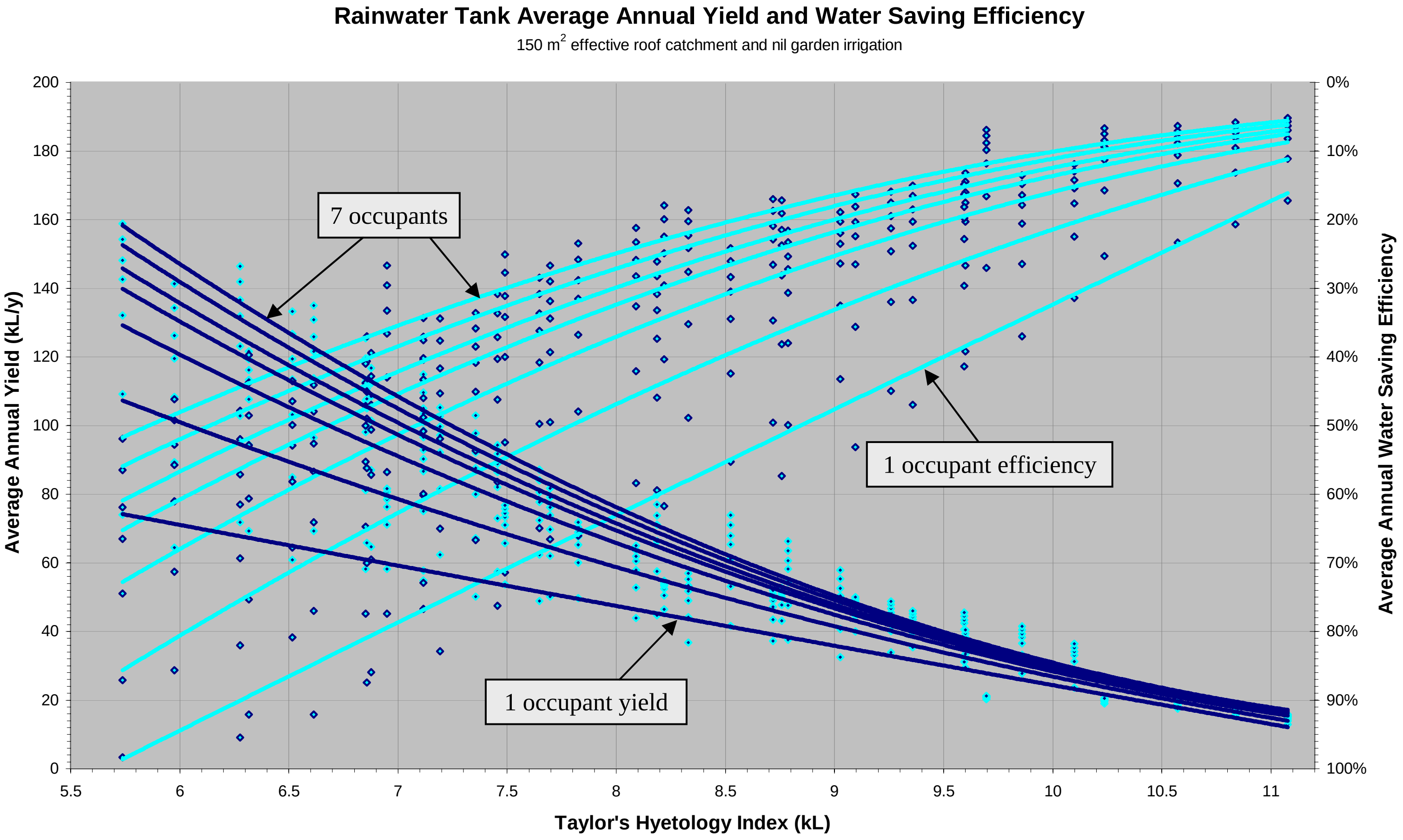

Figure 4.11 Hydrologic yield and water saving efficiency for 150 m^2 effective roof area and nil garden irrigation derived from THI and occupancy using polynomial regression

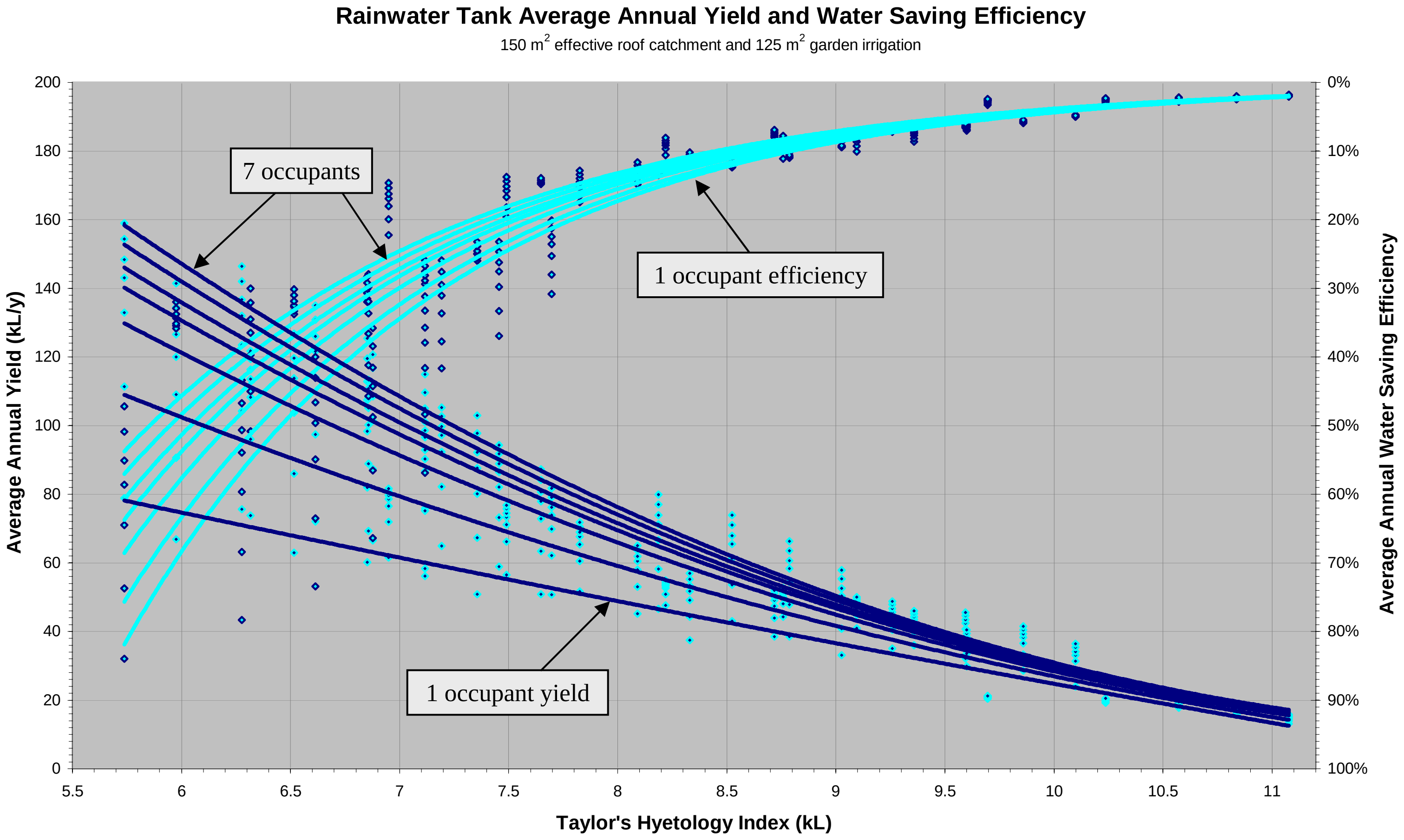

Figure 4.12 **Hydrologic yield and water saving efficiency for 150 m^2 effective roof area and 125 m^2 garden irrigation derived from THI and occupancy using polynomial and exponential regression, respectively**

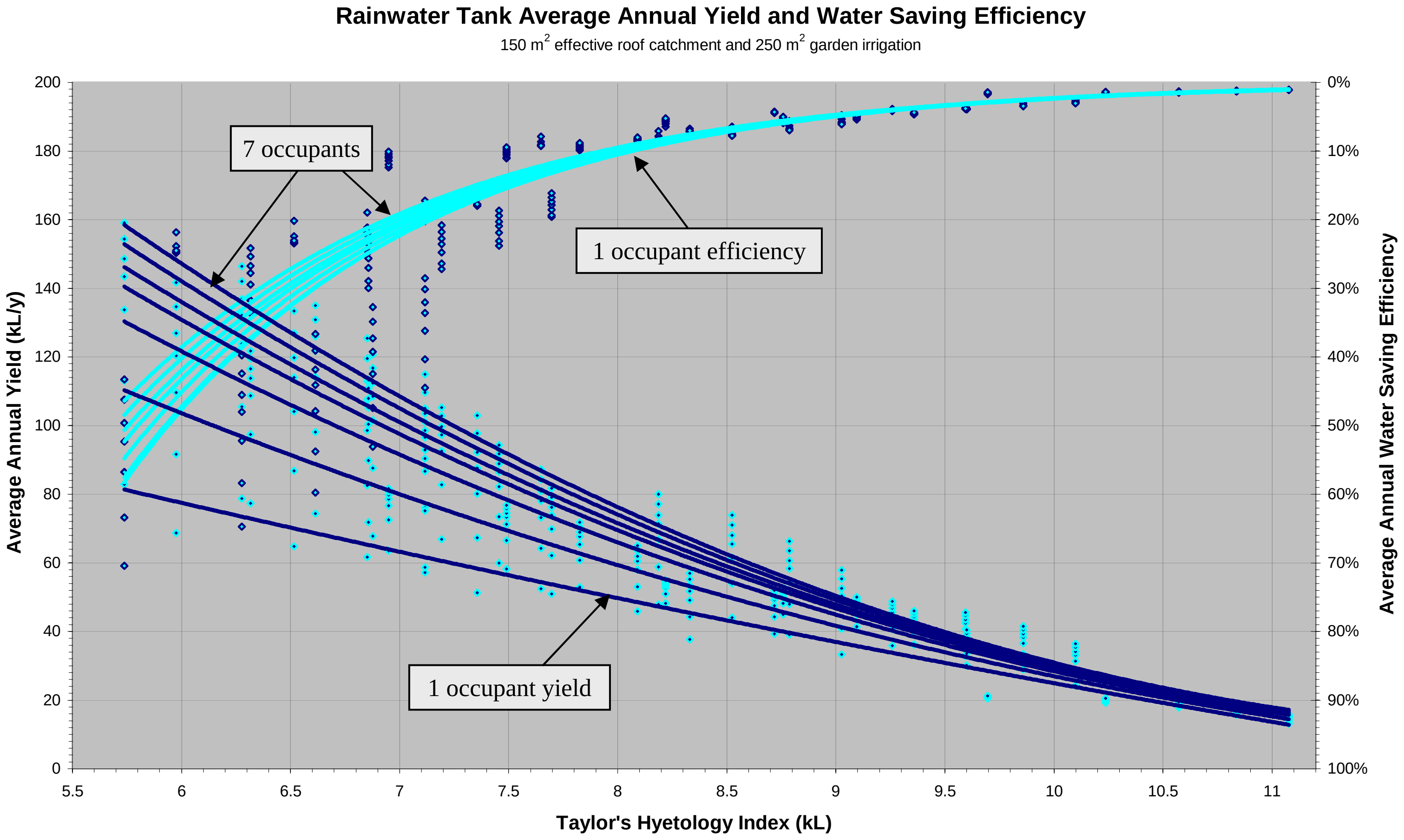

Figure 4.13 Hydrologic yield and water saving efficiency for 150 m^2 effective roof area and 250 m^2 garden irrigation derived from THI and occupancy using polynomial and exponential regression, respectively

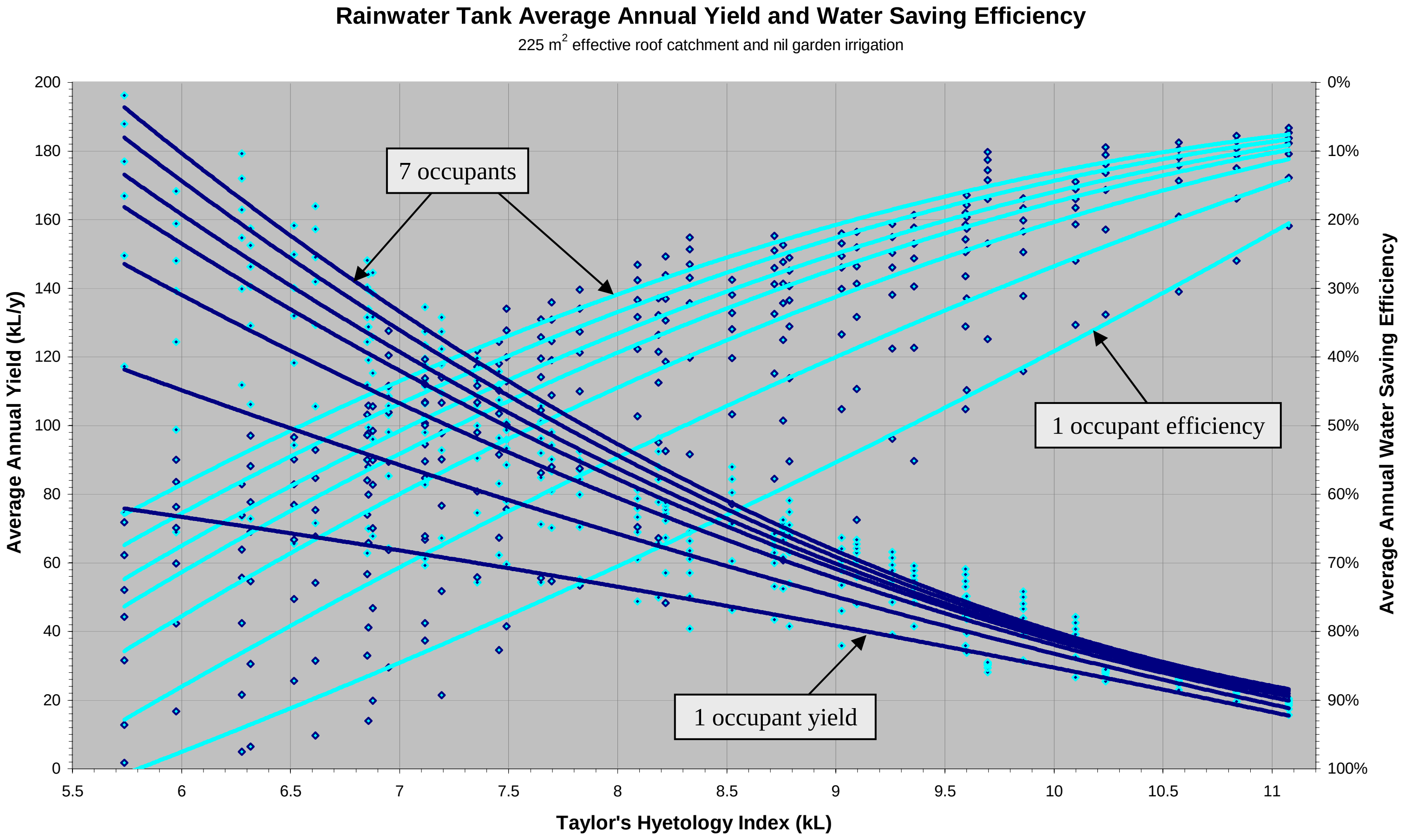

Figure 4.14 Hydrologic yield and water saving efficiency for 225 m^2 effective roof area and nil garden irrigation derived from THI and occupancy using polynomial regression

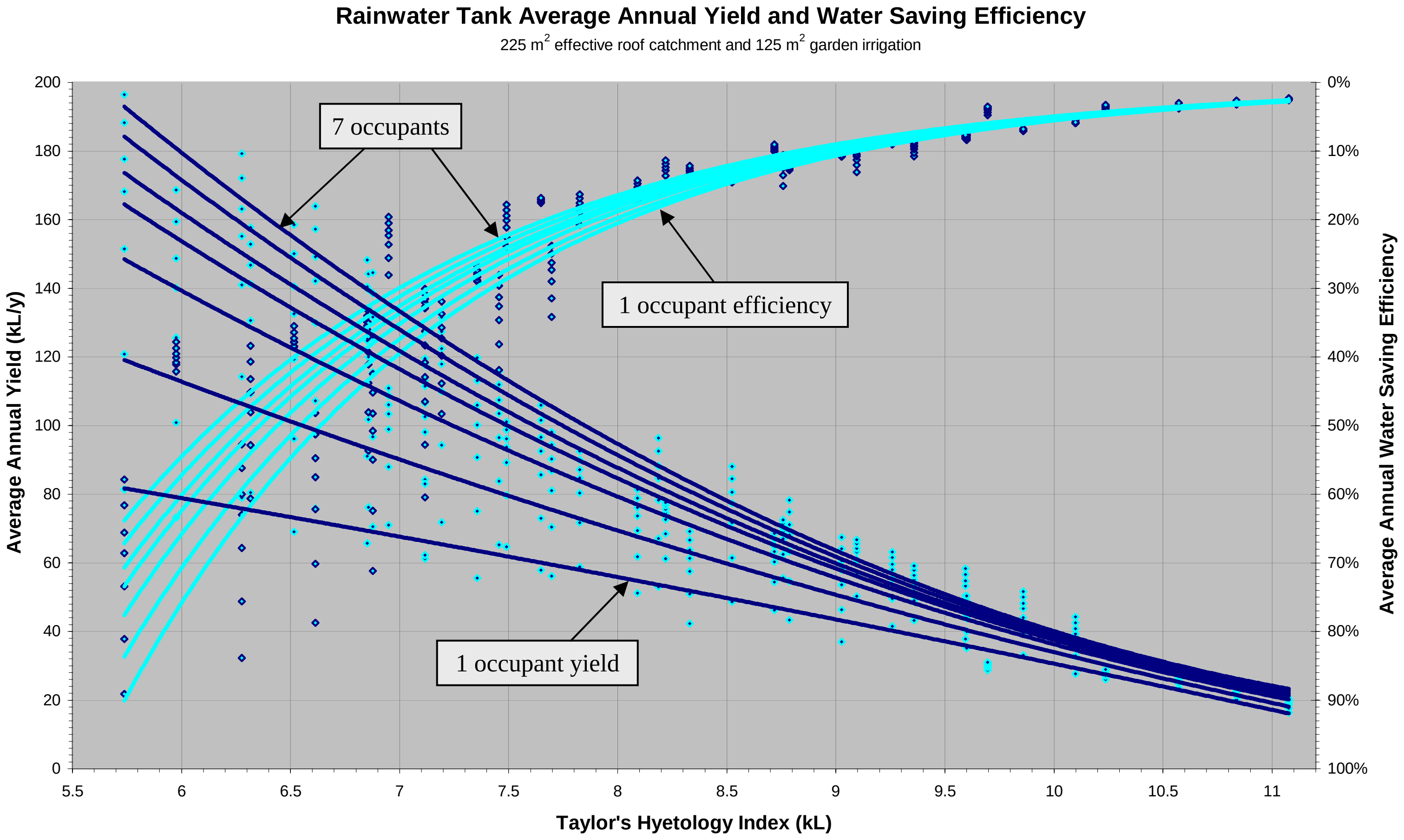

Figure 4.15 Hydrologic yield and water saving efficiency for 225 m^2 effective roof area and 125 m^2 garden irrigation derived from THI and occupancy using polynomial and exponential regression, respectively

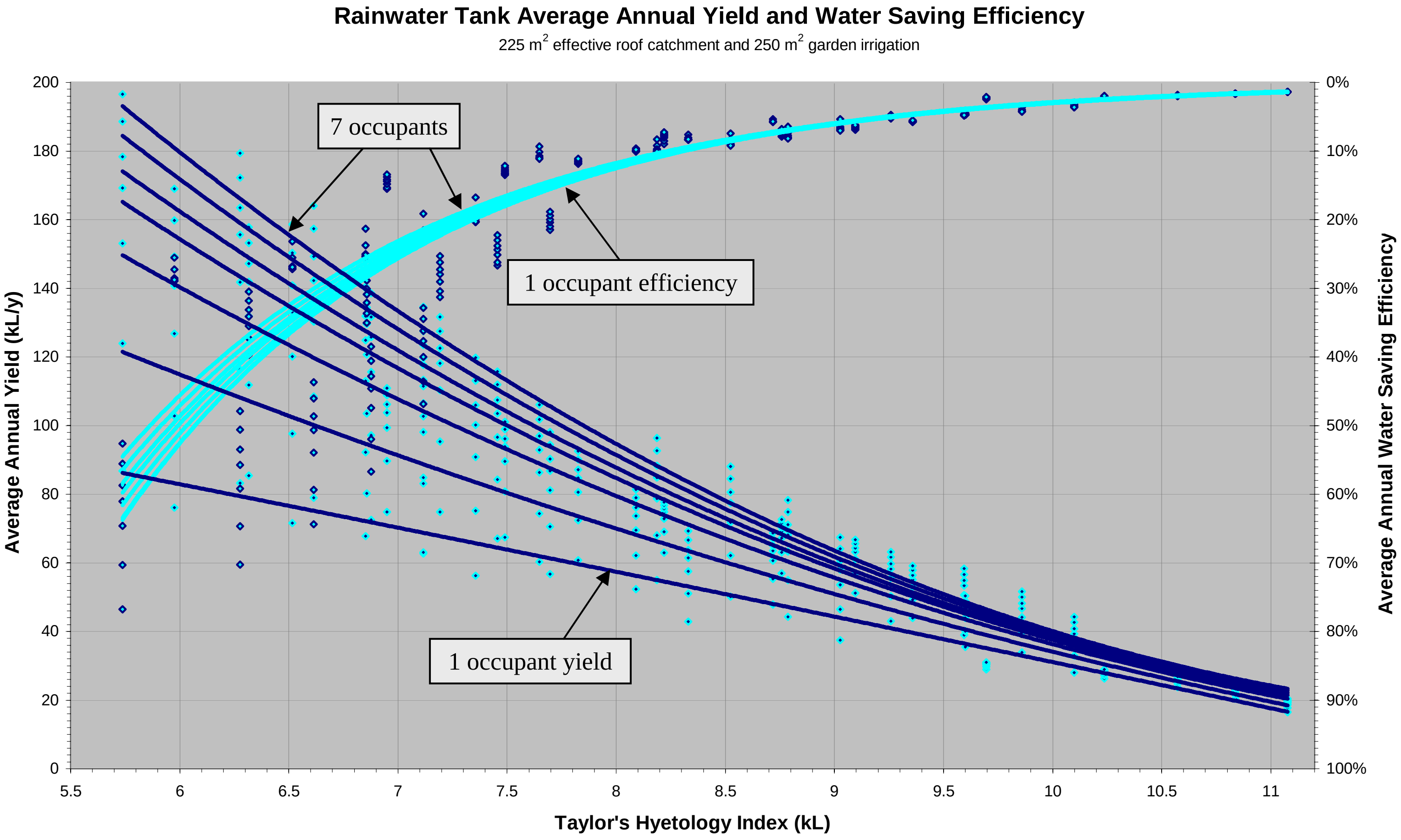

Figure 4.16 Hydrologic yield and water saving efficiency for 225 m^2 effective roof area and 250 m^2 garden irrigation derived from THI and occupancy using polynomial and exponential regression, respectively

Chapter 5

Conclusion

Conclusions will be presented in accordance with aims and objectives of the research. Some areas of further research are identified to enhance the results and increase research application.

5.1 Choice of simulation program

Aquacycle was chosen to simulate the rainwater tank mass balance from a short list of four programs, also including MUSIC, PURRS and Excel. Aquacycle was chosen by:

- Out ranking the other programs in terms of research appropriateness when considering a weighted performance criteria;
- Having rigorous functions suitable for the research simulation;
- Not limiting the quality of research results through assumptions and cautions; and
- Being accurately calibrated and validated to key research results.

5.2 Choice of simulation dimensions and parameters

Five simulation dimensions were established to ensure state-wide hydrologic yield and water saving efficiency trends could be established for the majority of existing and emerging development types. The dimensions included eight sites, three effective roof areas, three garden irrigation areas, five tank volumes and seven household occupancies. The product of the magnitude of these dimensions provides a total of 2520 unique simulations. The values within these dimensions and other input parameters were matched where possible to existing hydraulic yield and water saving efficiency research so the processes and results of this research can be easily reviewed.

5.3 Simulation site selection

Key simulation sites were chosen on the basis of providing a thorough representation of the climate classes within Queensland and having a good spatial dispersion. Sites chosen included Birdsville, Brisbane, Cairns, Caloundra, Charleville, Mount Isa, Rockhampton and Townsville. Seven of these sites represent the BOM climate classes from summer dominate greater than 1200 mm median annual rainfall to arid less than 350 mm median annual rainfall. The summer 650 mm to 1200 mm median annual rainfall class is represented by both Brisbane and Rockhampton to provide a good spatial dispersion. The difference in results between Brisbane and Rockhampton are significant which shows the climate classes alone are insufficient to determine hydrologic yields and water saving efficiencies.

5.4 Reproduction of key research benchmarks

Two key benchmarks were established as average annual hydrologic yield derived from average annual precipitation and water saving efficiency derived from seasonality index. Reproduction of the benchmarks was undertaken using current BOM data. The hydrologic yield benchmark showed very good overall polynomial regression, but lower confidence in the upper domain. Reproduction of the water saving efficiency benchmark showed very poor polynomial regression which suggested this method is flawed for trend discovery across Queensland. Both methods have low opportunity to factor out any of the five simulation dimensions due to their high dependence on site specific parameters.

5.5 Performance of Taylor’s Hyetology Index over research benchmarks

An alternative method of determining hydrologic yield and water saving efficiency was established on the principles of rainwater tank mass balance simulation failure in THI. THI is able to exceed benchmark results in a number of key areas including:

- Providing a higher hydrologic yield polynomial regression without the loss of confidence in the upper domain;
- Providing a markedly improved water saving efficiency regression to achieve very good results;
- Factoring out both the site and tank volume parameter dimensions; and
- Displaying both benchmarks from a single domain or chart which reduces the series of charts needed to represent Queensland to one tenth.

THI values have been included for many Queensland sites, as shown in Table E.1 of Appendix E, to ensure application of the research is not restricted.

5.6 Meeting the research aims

Common to the research aims is to increase the accuracy of hydrologic yield and water saving efficiency estimation across Queensland. The exceedance over key benchmark results clearly demonstrates this. Also common is to provide results in a straightforward manner. By reducing the number of charts needed from 90 to 9, keeping tank volume as nominal and supporting this research with a small table of THI values, the research is arguably straightforward to apply.

This research increases the accuracy and relevance of information on this topic which makes it easier to employ efficient environmentally friendly technology. The consequences being a reduction of potable water consumption, reduction of peak and volumetric stormwater discharge and reduction of pollutant discharge from the urban catchment. There are also significant social and environmental benefits that come from reducing catchment change affects.

5.7 Opportunities of to enhance research through further work

Some opportunities to enhance this research through further work and the consequential affects include:

- Extending the geographic scope to a national study to see how THI performs or can be enhanced to include southern states.
- Reviewing efficiency regression calculation to increase the regression confidence in the lower domain
- Increasing the upper limit of the tank dimension to consider households with dual or very large tanks.
- Increasing the magnitude and resolution of the effective roof area dimension to attempt to factor out another selection chart dependent parameter dimension.
- Increasing the magnitude and resolution of the irrigation area dimension to attempt to factor out another selection chart dependent parameter dimension.
- Reviewing the irrigation function of Aquacycle against empirical data to increase calibration convergence.
- Enabling grey water treatment function of Aquacycle to minimise tank irrigation demand, increase water saving efficiency estimates and increase the relevance to developments engaging superior water saving technology.

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Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111 / ENG 4112 Research Project
PROJECT SPECIFICATION

FOR: **BENJAMIN TAYLOR**

TOPIC: Improving Accuracy of Rainwater Tank Hydrologic Yield Estimation across Queensland

SUPERVISOR: Dr. Ian Brodie

ENROLMENT: ENG 4111 – S1, EXT, 2009
ENG 4112 – S2, EXT, 2009

PROJECT AIM: To improve the accuracy of rainwater tank hydrologic yield and water saving efficiency estimation across Queensland relevant to the majority of current and emerging development types.

PROGRAMME: Issue B, 12th October 2009

- Research a shortlist of rainwater tank mass balance simulation programs relevant to the project aims, objectives and resource constraints.
- Determine key research results to be used for calibration, validation and establishing project performance benchmarks.
- Adopt a simulation program and undertake a detailed review of the functions, assumptions, cautions, and capacity to calibrate and validate against key research results.
- Establish parameter dimensions to envelope the climate range and majority of current and emerging development types that exists in Queensland.
- Analyse and reproduce key research results, using current BOM data, to establish project performance benchmarks.
- Establish parameter values commonly used in the topic to ensure research is accountable and easily reviewed.
- Discover alternative methods to determine hydrologic yield and water saving efficiency to increased accuracy over benchmarks.
- Present research results in a series of accurate charts with straightforward application suitable to homeowners and developers.

Agreed: ____________(Student) ____________
______(Supervisor)
__/__/__ __/__/__
Examiner / Co-examiner: ____

Appendix B

Aquacycle parameter files

Contents

B. 1 Extract of Climate data Brisbane

```
19700101,Brisbane Airport,20090618
19700101,0,5.5
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19700104,0,7
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19700109,0,6
19700110,0,5.7
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19700112,0,6.1
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```

B. 2 Indoor water usage profile

```
AdoptedIndoorConsumption
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2,38,122,112,71
3,49,166,147,124
4,56,196,180,155
5,60,216,201,178
6,72,245,226,204
7,84,273,252,229
0.6,0.5,0.25
```

B. 3 Unit block using nominal 3 kL rainwater tank

```
7
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```

B. 4 Unit block using nominal 5 kL rainwater tank

```
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```

B. 5 Unit block using nominal 7.2 kL rainwater tank

```
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```

B. 6 Unit block using nominal 10 kL rainwater tank

```
7
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0,8.5,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,8.5,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,8.5,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,8.5,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
```

B. 7 Unit block using nominal 14.5 kL rainwater tank

```
7
0,12.3,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,12.3,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,12.3,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,12.3,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,12.3,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,12.3,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,12.3,0,120,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
```

B. 8 Cluster

```
7
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
```

B. 9 Catchment

```
.63,0,0,0,0,0,0,0
```

B. 10 Measured and calibrated parameters and initial storage values for nil garden irrigation and 75 m^2 effective roof area

```
7
1,1,900,500,300,100,0,.09,0,0,0,0,0,0
1,2,900,500,300,100,0,.09,0,0,0,0,0,0
1,3,900,500,300,100,0,.09,0,0,0,0,0,0
1,4,900,500,300,100,0,.09,0,0,0,0,0,0
1,5,900,500,300,100,0,.09,0,0,0,0,0,0
1,6,900,500,300,100,0,.09,0,0,0,0,0,0
1,7,900,500,300,100,0,.09,0,0,0,0,0,0
0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
```

B. 11 Measured and calibrated parameters and initial storage values for nil garden irrigation and 150 m^2 effective roof area

```
7
1,1,900,500,300,100,0,.09,0,0,0,0,0,0
1,2,900,500,300,100,0,.09,0,0,0,0,0,0
1,3,900,500,300,100,0,.09,0,0,0,0,0,0
1,4,900,500,300,100,0,.09,0,0,0,0,0,0
1,5,900,500,300,100,0,.09,0,0,0,0,0,0
1,6,900,500,300,100,0,.09,0,0,0,0,0,0
1,7,900,500,300,100,0,.09,0,0,0,0,0,0
0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
```

```
2,0,0,0,0
2,0,0,0,0
```

B. 12 Measured and calibrated parameters and initial storage values for nil garden irrigation and 225 m^2 effective roof area

```
7
1,1,900,500,300,100,0,.09,0,0,0,0,0,0
1,2,900,500,300,100,0,.09,0,0,0,0,0,0
1,3,900,500,300,100,0,.09,0,0,0,0,0,0
1,4,900,500,300,100,0,.09,0,0,0,0,0,0
1,5,900,500,300,100,0,.09,0,0,0,0,0,0
1,6,900,500,300,100,0,.09,0,0,0,0,0,0
1,7,900,500,300,100,0,.09,0,0,0,0,0,0
0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
```

B. 13 Measured and calibrated parameters and initial storage values for 125 m^2 garden irrigation and 75 m^2 effective roof area

```
7
1,1,900,500,300,100,25,.09,0,0,0,0,0,0
1,2,900,500,300,100,25,.09,0,0,0,0,0,0
1,3,900,500,300,100,25,.09,0,0,0,0,0,0
1,4,900,500,300,100,25,.09,0,0,0,0,0,0
1,5,900,500,300,100,25,.09,0,0,0,0,0,0
1,6,900,500,300,100,25,.09,0,0,0,0,0,0
1,7,900,500,300,100,25,.09,0,0,0,0,0,0
0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
```

```
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
```

B. 14 Measured and calibrated parameters and initial storage values for 125 m^2 garden irrigation and 150 m^2 effective roof area

```
7
1,1,900,500,300,100,25,.09,0,0,0,0,0,0
1,2,900,500,300,100,25,.09,0,0,0,0,0,0
1,3,900,500,300,100,25,.09,0,0,0,0,0,0
1,4,900,500,300,100,25,.09,0,0,0,0,0,0
1,5,900,500,300,100,25,.09,0,0,0,0,0,0
1,6,900,500,300,100,25,.09,0,0,0,0,0,0
1,7,900,500,300,100,25,.09,0,0,0,0,0,0
0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
```

B. 15 Measured and calibrated parameters and initial storage values for 125 m^2 garden irrigation and 225 m^2 effective roof area

```
7
1,1,900,500,300,100,25,.09,0,0,0,0,0,0
1,2,900,500,300,100,25,.09,0,0,0,0,0,0
1,3,900,500,300,100,25,.09,0,0,0,0,0,0
```

```
1,4,900,500,300,100,25,.09,0,0,0,0,0,0
1,5,900,500,300,100,25,.09,0,0,0,0,0,0
1,6,900,500,300,100,25,.09,0,0,0,0,0,0
1,7,900,500,300,100,25,.09,0,0,0,0,0,0
0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
```

B. 16 Measured and calibrated parameters and initial storage values for 250 m^2 garden irrigation and 75 m^2 effective roof area

```
7
1,1,900,500,300,100,50,.09,0,0,0,0,0,0
1,2,900,500,300,100,50,.09,0,0,0,0,0,0
1,3,900,500,300,100,50,.09,0,0,0,0,0,0
1,4,900,500,300,100,50,.09,0,0,0,0,0,0
1,5,900,500,300,100,50,.09,0,0,0,0,0,0
1,6,900,500,300,100,50,.09,0,0,0,0,0,0
1,7,900,500,300,100,50,.09,0,0,0,0,0,0
0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,25,2,0,0,100,0,0,0,0,0,.31,0
0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
```

B. 17 Measured and calibrated parameters and initial storage values for 250 m^2 garden irrigation and 150 m^2 effective roof area

```
7
1,1,900,500,300,100,50,.09,0,0,0,0,0,0
1,2,900,500,300,100,50,.09,0,0,0,0,0,0
1,3,900,500,300,100,50,.09,0,0,0,0,0,0
1,4,900,500,300,100,50,.09,0,0,0,0,0,0
1,5,900,500,300,100,50,.09,0,0,0,0,0,0
1,6,900,500,300,100,50,.09,0,0,0,0,0,0
1,7,900,500,300,100,50,.09,0,0,0,0,0,0
0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,50,2,0,0,100,0,0,0,0,0,.31,0
0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
```

B. 18 Measured and calibrated parameters and initial storage values for 250 m^2 garden irrigation and 225 m^2 effective roof area

```
7
1,1,900,500,300,100,50,.09,0,0,0,0,0,0
1,2,900,500,300,100,50,.09,0,0,0,0,0,0
1,3,900,500,300,100,50,.09,0,0,0,0,0,0
1,4,900,500,300,100,50,.09,0,0,0,0,0,0
1,5,900,500,300,100,50,.09,0,0,0,0,0,0
1,6,900,500,300,100,50,.09,0,0,0,0,0,0
1,7,900,500,300,100,50,.09,0,0,0,0,0,0
0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
22,32,240,1,75,2,0,0,100,0,0,0,0,0,.31,0
0
2,0,0,0,0
```

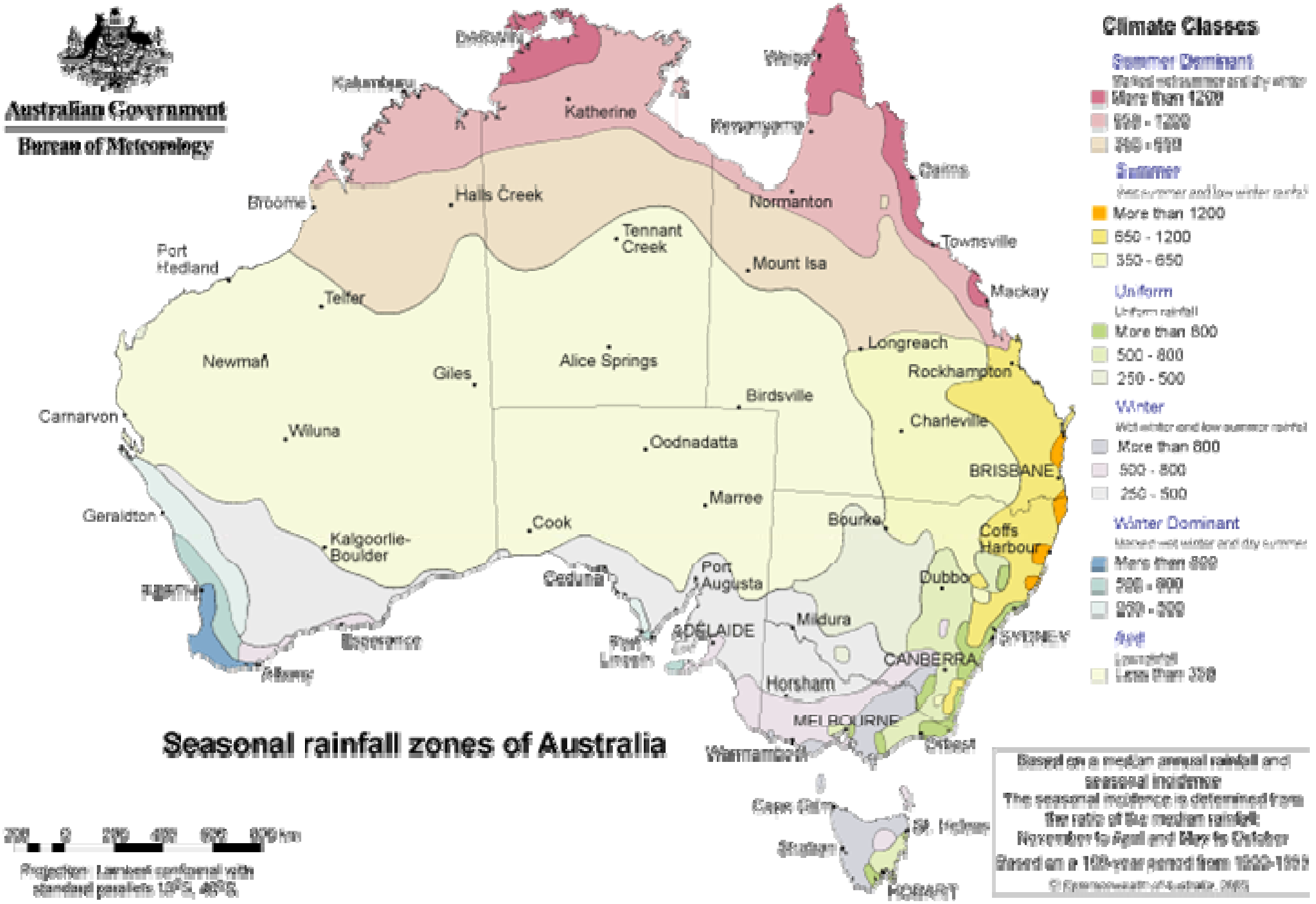
```
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
2,0,0,0,0
```

Appendix C

Bureau of Meteorology charts and data

Contents

C. 1 Seasonal rainfall zones of Australia



C. 2 Extract of BOM data for Brisbane

```
"17701231" 365 31/12/1770 -99.9 999 -99.9 999 9999.9 999 999.9 999 999.9  999 999.9 999 9999.9 9999.9 9999.9
""
" This file is SPACE DELIMITED for easy import into both spreadsheets and programs."
"The first line 17701231 contains dummy data and is provided to allow spreadsheets to sense the columns"
" To read into a spreadsheet select DELIMITED and SPACE."
" "
" "
"=========  The following essential information and notes should be kept in the data file =========="
" "
"The Data Drill system and data are copyright to the Queensland Govt, Natural Resources and Mines."
"The data are supplied to the licencee only and may not be given, lent, or sold to any other party"
" "
"Notes:"
" * Data Drill for Lat, Long: -27.40 153.15 (DECIMAL DEGREES), 27 24'S 153 09'E Your Ref: BrisbaneAP"
" * Extracted from Silo on 20090619"
" * Please read the documentation on the Data Drill at http://www.nrm.qld.gov.au/silo"
" "
" * As evaporation is read at 9am, it has been shifted to the day before"
"    ie The evaporation measured on 20 April is in row for 19 April"
" * The 6 Source columns Smx-Svp indicate the source of the data to their left"
" "
"   25 = interpolated daily observations,     75 = interpolated long term average"
"   26 = synthetic pan evaporation "
" "
" * Relative Humidity has been calculated using 9am VP, T.Max and T.Min"
"   RHmaxT is estimated Relative Humidity at Temperature T.Max"
"   RHminT is estimated Relative Humidity at Temperature T.Min"
" * FAO56 = Potential Evapotranspiration calculated using the FAO Penman-Monteith formula as in"
"   FAO Irrigation and Drainage paper 56,  http://www.fao.org/docrep/X0490E/X0490E00.htm"
" * As the evapotranspiration has been calculated from other data, particularly, Tmax, Tmin, Rad, and VP,"
"   its accuracy and source code are dependant on the source and accuracy of the data in those columns."
" * The accuracy of the data depends on many factors including date, location, and variable"
"   for consistency data is supplied using one decimal place, however it is not accurate to that precision."
```

```
"   Further information is available from http://www.nrw.qld.gov.au/silo"
"=========================================================================================="
" "
Date       Day Date2      T.Max Smx T.Min Smn Rain   Srn  Evap Sev Radn   Ssl VP    Svp RHmaxT RHminT  FAO56
(yyyymmdd)  () (ddmmyyyy)  (oC)  ()  (oC)  ()   (mm)  ()  (mm)  () (MJ/m2) () (hPa)  ()   (%)    (%)    (mm)
19700101     1  1-01-1970  29.5  25  22.0  25    0.0  25   9.0  25  25.0   25  23.0  25   55.8   87.0    5.5
19700102     2  2-01-1970  29.0  25  20.5  25   31.0  25   9.8  25  28.0   25  10.0  25   25.0   41.5    6.9
19700103     3  3-01-1970  30.0  25  17.5  25    0.0  25   8.2  25  31.0   25  15.0  25   35.4   75.0    6.7
19700104     4  4-01-1970  31.5  25  19.5  25    0.0  25   9.4  25  31.0   25  17.0  25   36.8   75.0    7.0
19700105     5  5-01-1970  33.0  25  19.5  25    0.0  25   8.6  25  31.0   25  20.0  25   39.8   88.3    7.0
19700106     6  6-01-1970  32.0  25  21.0  25    0.0  25   9.8  25  29.0   25  26.0  25   54.7  100.0    6.2
19700107     7  7-01-1970  30.0  25  23.0  25    0.0  25   5.8  25  25.0   25  23.0  25   54.2   81.9    5.7
19700108     8  8-01-1970  29.0  25  21.0  25    0.0  25   6.0  25  24.0   25  23.0  25   57.4   92.5    5.2
19700109     9  9-01-1970  29.0  25  20.5  25    0.0  25   5.6  25  28.0   25  20.0  25   49.9   83.0    6.0
19700110    10 10-01-1970  29.5  25  21.0  25    0.0  25   6.8  25  27.0   25  23.0  25   55.8   92.5    5.7
19700111    11 11-01-1970  31.0  25  22.5  25    0.0  25   9.0  25  29.0   25  23.0  25   51.2   84.4    6.4
19700112    12 12-01-1970  31.5  25  23.0  25    0.0  25   7.4  25  27.0   25  25.0  25   54.1   89.0    6.1
19700113    13 13-01-1970  32.5  25  22.0  25    4.7  25   7.0  25  21.0   25  27.0  25   55.2  100.0    5.0
19700114    14 14-01-1970  31.5  25  21.5  25    1.5  25   6.4  25  21.0   25  26.0  25   56.3  100.0    4.9
19700115    15 15-01-1970  28.5  25  22.0  25   23.9  25   5.6  25  16.0   25  24.0  25   61.7   90.8    3.9
19700116    16 16-01-1970  29.0  25  21.5  25    0.0  25   4.8  25  24.0   25  21.0  25   52.4   81.9    5.4
19700117    17 17-01-1970  30.5  25  21.0  25    0.2  25   8.2  25  25.0   25  24.0  25   55.0   96.5    5.5
19700118    18 18-01-1970  31.0  25  22.0  25    0.0  25   5.6  25  20.0   25  25.0  25   55.6   94.6    4.8
19700119    19 19-01-1970  32.0  25  22.0  25    0.0  25   7.4  25  26.0   25  27.0  25   56.8  100.0    5.7
19700120    20 20-01-1970  32.0  25  23.5  25    1.1  25   4.4  25  28.0   25  28.0  25   58.9   96.7    6.1
19700121    21 21-01-1970  32.5  25  24.0  25    0.0  25   6.4  25  25.0   25  27.0  25   55.2   90.5    5.8
19700122    22 22-01-1970  27.5  25  18.5  25   57.2  25   4.4  25  24.0   25  22.0  25   59.9  100.0    4.7
19700123    23 23-01-1970  29.0  25  18.5  25    0.7  25   4.6  25  29.0   25  17.0  25   42.4   79.9    6.2
19700124    24 24-01-1970  29.5  25  21.5  25    0.0  25   7.2  25  27.0   25  21.0  25   50.9   81.9    5.9
19700125    25 25-01-1970  30.5  25  22.5  25    0.0  25   7.2  25  23.0   25  26.0  25   59.6   95.4    5.1
19700126    26 26-01-1970  30.5  25  22.5  25    0.0  25   5.0  25  27.0   25  22.0  25   50.4   80.7    6.1
19700127    27 27-01-1970  30.5  25  21.5  25    0.0  25   5.6  25  19.0   25  24.0  25   55.0   93.6    4.6
19700128    28 28-01-1970  27.5  25  22.5  25    0.3  25   2.8  25  11.0   25  24.0  25   65.4   88.1    3.1
19700129    29 29-01-1970  24.0  25  21.5  25   27.6  25   0.4  25  10.0   25  24.0  25   80.5   93.6    2.3
19700130    30 30-01-1970  26.5  25  20.0  25   44.8  25   1.6  25  10.0   25  24.0  25   69.3  100.0    2.5
19700131    31 31-01-1970  28.0  25  20.5  25   13.2  25   6.0  25  17.0   25  25.0  25   66.1  100.0    3.7
```

19700201	32	1-02-1970	28.5	25	19.5	25	0.0	25	7.0	25	21.0	25	18.0	25	46.3	79.4	5.0
19700202	33	2-02-1970	28.0	25	20.0	25	0.3	25	5.4	25	21.0	25	21.0	25	55.6	89.9	4.6
19700203	34	3-02-1970	29.0	25	20.5	25	0.6	25	3.6	25	22.0	25	22.0	25	54.9	91.3	4.9
19700204	35	4-02-1970	28.0	25	20.0	25	10.7	25	4.6	25	18.0	25	22.0	25	58.2	94.1	4.1
19700205	36	5-02-1970	28.5	25	20.5	25	1.4	25	1.8	25	20.0	25	24.0	25	61.7	99.6	4.3
19700206	37	6-02-1970	28.0	25	19.5	25	0.0	25	4.4	25	12.0	25	22.0	25	58.2	97.1	3.2
19700207	38	7-02-1970	29.0	25	20.5	25	0.2	25	5.8	25	19.0	25	22.0	25	54.9	91.3	4.5
19700208	39	8-02-1970	28.5	25	21.0	25	2.6	25	6.8	25	25.0	25	22.0	25	56.5	88.5	5.3
19700209	40	9-02-1970	28.5	25	20.0	25	2.5	25	4.8	25	20.0	25	25.0	25	64.3	100.0	4.1
19700210	41	10-02-1970	28.0	25	20.0	25	0.6	25	5.4	25	25.0	25	20.0	25	52.9	85.6	5.3
19700211	42	11-02-1970	28.5	25	20.5	25	1.0	25	6.2	25	22.0	25	21.0	25	54.0	87.1	4.9
19700212	43	12-02-1970	28.0	25	21.0	25	0.1	25	5.4	25	22.0	25	21.0	25	55.6	84.5	4.9
19700213	44	13-02-1970	30.0	25	20.0	25	0.0	25	5.2	25	21.0	25	21.0	25	49.5	89.9	4.9
19700214	45	14-02-1970	28.5	25	20.5	25	0.1	25	5.0	25	24.0	25	22.0	25	56.5	91.3	5.0
19700215	46	15-02-1970	29.5	25	20.5	25	0.2	25	9.4	25	26.0	25	21.0	25	50.9	87.1	5.6
19700216	47	16-02-1970	29.5	25	21.5	25	0.0	25	6.8	25	25.0	25	23.0	25	55.8	89.7	5.3
19700217	48	17-02-1970	30.5	25	22.0	25	0.0	25	5.2	25	18.0	25	21.0	25	48.1	79.5	4.8
19700218	49	18-02-1970	29.5	25	20.0	25	33.1	25	5.6	25	26.0	25	24.0	25	58.2	100.0	5.2
19700219	50	19-02-1970	30.0	25	21.0	25	0.0	25	5.6	25	26.0	25	24.0	25	56.6	96.5	5.4
19700220	51	20-02-1970	31.0	25	23.0	25	0.0	25	7.0	25	25.0	25	27.0	25	60.1	96.1	5.4
19700221	52	21-02-1970	30.0	25	23.5	25	10.7	25	5.2	25	21.0	25	27.0	25	63.6	93.3	4.7
19700222	53	22-02-1970	29.0	25	22.5	25	8.7	25	3.8	25	18.0	25	27.0	25	67.4	99.1	3.9
19700223	54	23-02-1970	27.5	25	22.0	25	33.0	25	6.6	25	17.0	25	25.0	25	68.1	94.6	3.7
19700224	55	24-02-1970	25.5	25	21.0	25	8.3	25	2.2	25	11.0	25	23.0	25	70.5	92.5	2.7

Appendix D

MathWorks MATLAB code files

Contents

D. 1 concat.m

```
% concat.m  concatenates the average annual results from
%           Aquacycle into a single Microsoft Excel spreadsheet
%           file
%
% INPUT:    ClusterYearly#.csv (Aquacycle simulation output)
%
% OUTPUT:   ?????.xls (file name defined through user grouping
%           assignment)
%
% Programmed by Benjamin Taylor (W0016682)
% Last updated 11-10-2009   - additional comments added
=================================================================

clear;clc

head=42;                            %header rows to ignore
tankssize=[3,5,7.2,10,14.5];        %nominal tank volume range
roofsize=[.25*300,.5*300,.75*300];  %effective roof area range
gardensize=[0,.25*500,.5*500];      %garden irrigation area range

% define filename and path components
od={'D:\Uni\BEng (Civil)\BEng Courses\`0901 ENG4111 - Research
Project Part 1\AquaCycle\Simulations\'};
sites={'BIRDSVILLE\','BRISBANE\','CAIRNS\','CHARLEVILL\','COLOUNDRA\
',...
    'MT ISA\','ROCKHAMPTON\','TOWNSVILLE\'};
rooves={'ROOF 25%\','ROOF 50%\','ROOF 75%\'};
gardens={'GARDEN 0%\','GARDEN 25%\','GARDEN 50%\'};
tanks={'TANK 2kL\','TANK 5kL\','TANK 7.2kL\','TANK 10kL\','TANK
14.5kL\'};
occupants={'ClusterYearly1.csv','ClusterYearly2.csv',...

'ClusterYearly3.csv','ClusterYearly4.csv','ClusterYearly5.csv',...
    'ClusterYearly6.csv','ClusterYearly7.csv'};

% define format of input file
frmt=['%q%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f6
4%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f6
4%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f6
4%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f6
4%f64*[^\n]'];

% Query user for data groupings
prompt={'Include sites: (a=all 1=brid 2=bris 3=cair 4=char 5=colo
6=mt.I 7=rock 8=tvle)',...
    'Roof areas: (a=all 1=25% 2=50% 3=75%)',...
    'Garden areas: (a=all 1=0% 2=25% 3=50%)',...
    'Tank sizes: (a=all 1=3kL 2=5kL 3=7.2kL 4=10kL 5=14.5kL)',...
    'Occupancies: (a=all and 1-7)'};
name='simulation groupings';
numlines=1;
if exist('rerun') == 1
    defaultanswer={char(gp(1,1)),char(gp(2,1)),char(gp(3,1)),...
```

```
        char(gp(4,1)),char(gp(5,1))};
else
    defaultanswer={'2','1','1','1','1'};
end
gp=inputdlg(prompt,name,numlines,defaultanswer);

% determine and combine records
if char(gp(1,1))=='a'
    %All sites
    sitenum=8;
else
    %Single site
    sitenum=1;
end
if char(gp(2,1))=='a'
    %All rooves
    roofnum=3;
else
    %Single roof
    roofnum=1;
end
if char(gp(3,1))=='a'
    %All gardens
    gardennum=3;
else
    %Single garden
    gardennum=1;
end
if char(gp(4,1))=='a'
    %All tanks
    tanknum=5;
else
    %Single tank
    tanknum=1;
end
if char(gp(5,1))=='a'
    %All occupancies
    occupnum=7;
else
    %Single occupancy
    occupnum=1;
end

% display waitbar
simnum=sitenum*roofnum*gardennum*tanknum*occupnum;
step=0;
msg=waitbar(0,'Processing, please wait');

for sitestep = 1:sitenum    %cycle through site dimension
    if sitenum ==1
        site=char(sites(1,str2num(char(gp(1,1)))));
        sitecode=char(gp(1,1));
    else
        site=char(sites(1,sitestep));
        sitecode=num2str(sitestep);
    end
    for roofstep = 1:roofnum    %cycle through effective roof
dimension
```

```
        if roofnum ==1
            roof=char(rooves(1,str2num(char(gp(2,1)))));
            roofcode=roofsize(1,str2num(char(gp(2,1))));
        else
            roof=char(rooves(1,roofstep));
            roofcode=roofsize(1,roofstep);
        end
        for gardenstep = 1:gardennum    %cycle through garden
irrigation dimension
            if gardennum ==1
                garden=char(gardens(1,str2num(char(gp(3,1)))));
                gardencode=gardensize(1,str2num(char(gp(3,1))));
            else
                garden=char(gardens(1,gardenstep));
                gardencode=gardensize(1,gardenstep);
            end
            for tankstep = 1:tanknum    %cycle through tank volume
dimension
                if tanknum ==1
                    tank=char(tanks(1,str2num(char(gp(4,1)))));
                    tankcode=tankssize(1,str2num(char(gp(4,1))));
                else
                    tank=char(tanks(1,tankstep));
                    tankcode=tankssize(1,tankstep);
                end
                for occupstep = 1:occupnum  %cycle through occpuancy
dimension
                    if occupnum ==1

occup=char(occupants(1,str2num(char(gp(5,1)))));
                        occupcode=char(gp(5,1));
                    else
                        occup=char(occupants(1,occupstep));
                        occupcode=num2str(occupstep);
                    end

                    %update wait bar message
                    step=step+1;
                    waitbar(step/simnum,msg);

                    %locate and read in Aquacycle simulation results
                    filename=occup;

pathname=sprintf('%s',char(od),site,roof,garden,tank);
                    fid=fopen([pathname,filename]);
                    sim=textscan(fid, frmt,'delimiter',',',...
                        'headerlines',head,'emptyvalue',NaN);

                    %reduce simulation results to only enabled sub
processes
                    rsim=cat(2,sim(1,2:6),sim(1,8:9),sim(1,13:22),...

sim(1,24:26),sim(1,29),sim(1,33:35),sim(1,63:64));
                    fclose('all');

                    %assign unique index to simulation data record
```

```
rowcode=[str2num(sitecode),roofcode,gardencode,...
                        tankcode,str2num(occupcode)];
                    if step ==1
                        sims=rsim;
                        rowcodes=rowcode;
                    else
                        sims=cat(1,sims,rsim);
                        rowcodes=cat(1,rowcodes,rowcode);
                    end
                end
            end
        end
    end
end

%close wait bar and opened Aquacycle simulation files
close(msg);
fclose('all');

%define output file name from user group selection
fileout=sprintf('%s',cell2mat(gp'),'.xls');
if size(sims,1)==simnum     %correct data length and proceed
    target=sprintf('A2:AE%.0f',simnum+1);
    out=cat(2,rowcodes,cell2mat(sims));

    %write output file
    xlswrite(fileout,out,target);

    %display notice and question to repeat to user
    fprintf('%.0f Simulation(s) combined into %s\n',simnum,fileout);
    usrquest=input('generate a new file (y/n)? ','s');
    if usrquest== 'y'
        rerun='ok';
        concat
    else
        clear;
    end
else                        %incorrect data length abort output
    fprintf('some simulation errors, check for missing data files');
end
%EOF
```

D. 2 si.m

```
% si.m      calculates Summer's seasonality index
%
% INPUT:    Compatible file is data drill space delimited FAO56
%           Bureau of Meteorology (BOM)
%
% OUTPUT:   sindex (the seasonality index for the BOM site
%           selected)
%
% Programmed by Benjamin Taylor (W0016682)
% Last updated 11-10-2009   - additional comments added
=================================================================

clear;
clc;

head=38;    %header rows to ignore

%prompt for BOM data file
[filename, pathname] = uigetfile('Bureau Data.txt', 'Select Bureau
text file');
if filename == 0 % user pressed cancel so offer a retry
    gui=questdlg('No Data Selected','Exit
Dialog','Retry','Cancel','Retry');
    switch gui
        case 'Retry', %allow user to retry
            si
        case 'Cancel', %allow user to cancel
            clear filename gui pathname %clears all working
variables
            fprintf('\nUser cancelled operation!\n')
    end
else

    %open and read BOM file
    fid=fopen([pathname,filename]);

frmt=['%n%n%s%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f6
4%f64'];
    bdata=textscan(fid, frmt,'delimiter','
','multipleDelimsAsOne',1,...
        'headerlines',head,'emptyvalue',NaN);
    dates=datevec(bdata{1,3},'dd-mm-yyyy');

    %determine annual rainfalls
    yrain=0;
    ycount=1;
    maxyr=max(dates(:,1));
    minyr=min(dates(:,1));
    cyear=minyr;
    for rstep=1:size(dates,1)
        if dates(rstep,1)==cyear
            yrain=yrain+bdata{1,8}(rstep,1);
        else
            annualrain(ycount,1)=yrain;
```

```
            annualrain(ycount,2)=cyear;
            yrain=bdata{1,8}(rstep,1);
            ycount=ycount+1;
            cyear=dates(rstep,1);
        end
        annualrain(ycount,1)=yrain;
        annualrain(ycount,2)=cyear;
    end

    %determine monthly rainfalls
    mrain=0;
    mcount=1;
    ycount=1;
    cmth=1;
    for rstep=1:size(dates,1)
        if dates(rstep,2)==cmth
            mrain=mrain+bdata{1,8}(rstep,1);
        else
            mthrain(ycount,mcount)=mrain;
            mrain=bdata{1,8}(rstep,1);
            if mcount ==12
                ycount=ycount+1;
                mcount=1;
            else
                mcount=mcount+1;
            end
            cmth=dates(rstep,2);
        end
        mthrain(ycount,mcount)=mrain;
    end

    % calculate seasonal index
    sindex=0;
    ymedian=median(annualrain(1:39,1));
    for j=1:12
        sindex=sindex+abs(median(mthrain(1:39,j)-ymedian/12));
    end
    sindex=sindex/ymedian

end
fclose('all');
%EOF
```

D. 3 thi.m

```
% thi.m     Calculates Taylor's hyetology index and site failures
%
% INPUT:    Compatible file is data drill space delimited FAO56
%           Bureau of Meteorology (BOM)
%
% OUTPUT:   thindex -(Taylor's hyetology index for the BOM site
%                    selected)
%           failure -(number of days without rain and excess rain
%                    for the BOM site selected)
%
% Programmed by Benjamin Taylor (W0016682)
% Last updated 11-10-2009   - additional comments added
=================================================================

clear;
clc;

thindex=zeros(8,5);         %initalise thindex variable
head=38;                    %number of header rows to exclude

%initalise pathname and filenames for key BOM sites
pathname=['D:\Uni\BEng (Civil)\BEng Courses\`0901 ENG4111 - Research
Project Part 1\Data\'];
filename={'Birdsville.txt','BrisbaneAP.txt','Cairns.txt',...
    'Charlevill.txt','Coloundra.txt','MtIsa.txt',...
    'Rockhampton.txt','Townsville.txt'};
tank=[3,5,7.2,10,14.5];     %tank volume range (kL)
threshold=150;              %excess rainfall thresshold (mm)
excco=34;                   %excess regression coefficient

% load climate data
for dload=1:8               %cycle through eight data sets to be
loaded

    %open and load each data set
    fid=fopen([pathname,filename{1,dload}]);

frmt=['%n%n%s%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f64%f6
4%f64'];
    bdata(:,:,dload)=textscan(fid, frmt,'delimiter',' ',...
        'multipleDelimsAsOne',1,'headerlines',head,'emptyvalue',NaN);

    % Calculate THI
    for tstep=1:5           %cycle through five tank volumes
        drycount=0;
        exccount=0;
        excsum=0;
        for rstep=1:length(bdata{1,1,1})    %cycle through each BOM
record
            if bdata{1,8,dload}(rstep,1)==0
                drycount=drycount+1;
            elseif bdata{1,8,dload}(rstep,1)>threshold
                exccount=exccount+1;
```

```
                excsum=excsum+bdata{1,8,dload}(rstep,1);
            end
        end
        failure(dload,1)=drycount;
        failure(dload,2)=exccount;

        %calculated THI
        thindex(dload,tstep)=(drycount+excco*exccount)/...
            length(bdata{1,1,1})*12.5-0.12*tank(tstep);
    end
end
fclose('all');

%output results
thindex
failure
%EOF
```

Appendix E

Taylor’s Hyetology Indexes throughout Queensland

Table E.1 Taylor’s Hyetology Indexation by site and nominal tanks size for Queensland

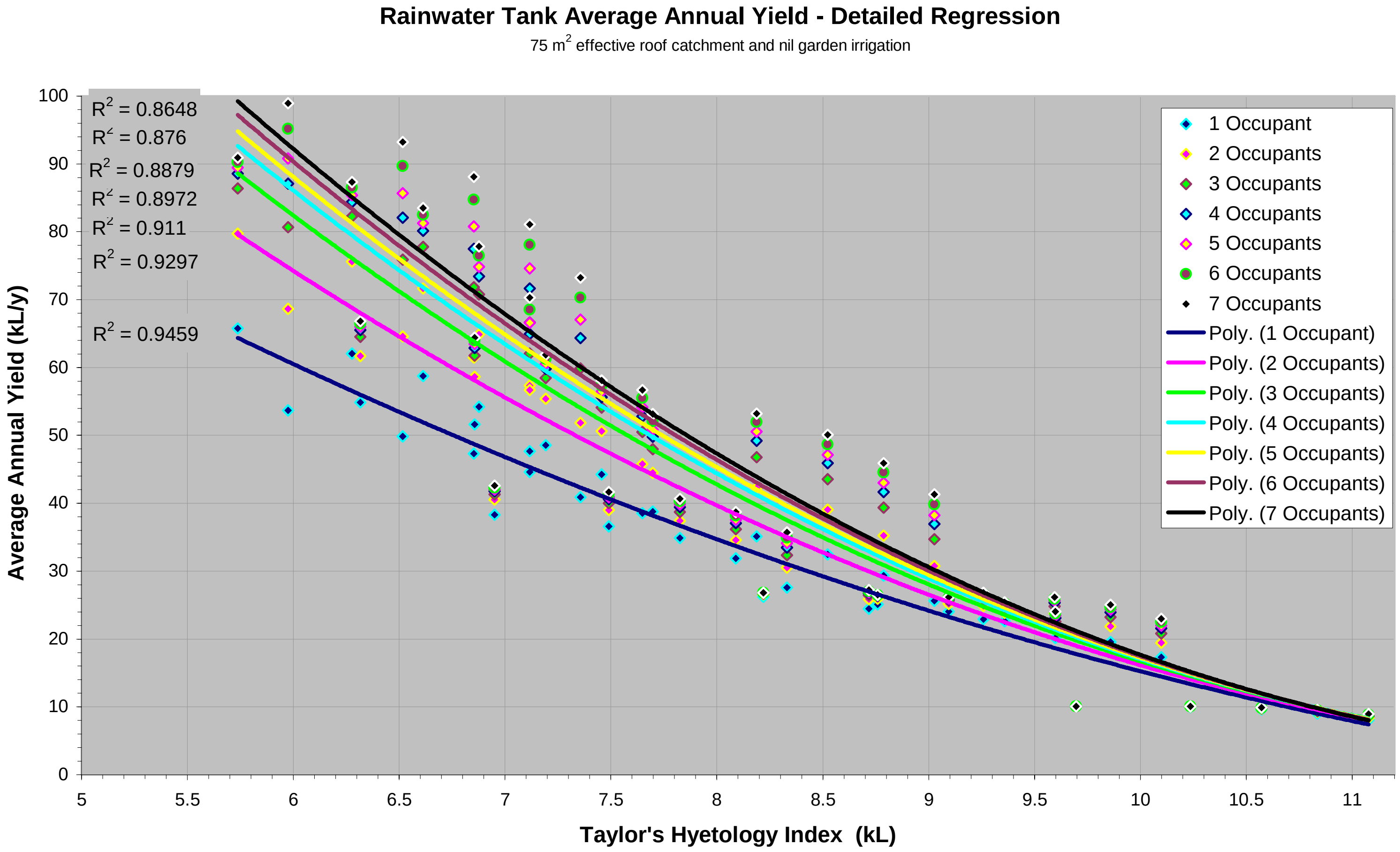
Site	D_{dry} **(days)**	D_{150} **(days)**	**Taylor’s Hyetology index (kL) by nominal rainwater tank volume (kL)**				
			3	**5**	**7.2**	**10**	**14.5**
Birdsville*	13188	0	11.08	10.84	10.57	10.24	9.70
Brisbane*	9052	7	7.70	7.46	7.19	6.86	6.32
Bundaberg	9062	12	7.79	7.55	7.29	6.95	6.41
Cairns*	7129	52	7.36	7.12	6.85	6.52	5.98
Caloundra*	8146	14	7.12	6.88	6.61	6.28	5.74
Charleville*	11484	0	9.60	9.36	9.10	8.76	8.22
Charters Towers	11168	3	9.34	9.10	8.83	8.50	7.96
Coolangatta	7739	27	7.09	6.85	6.59	6.25	5.71
Gladstone	9866	9	8.39	8.15	7.89	7.55	7.01
Ipswich	9701	5	8.13	7.89	7.63	7.29	6.75
Longreach	12395	2	10.36	10.12	9.86	9.52	8.98
Mackay	7983	34	7.50	7.26	7.00	6.66	6.12
Maryborough	8628	7	7.27	7.03	6.77	6.43	5.89
Mount Isa*	12026	1	10.10	9.86	9.59	9.26	8.72
Rockhampton*	9749	8	8.33	8.09	7.83	7.49	6.95
Toowoomba	9337	0	7.67	7.43	7.17	6.83	6.29
Townsville*	10043	23	9.03	8.79	8.52	8.19	7.65
Urangan	8191	3	6.78	6.54	6.27	5.94	5.40

* Sites used for regression of THI coefficients.

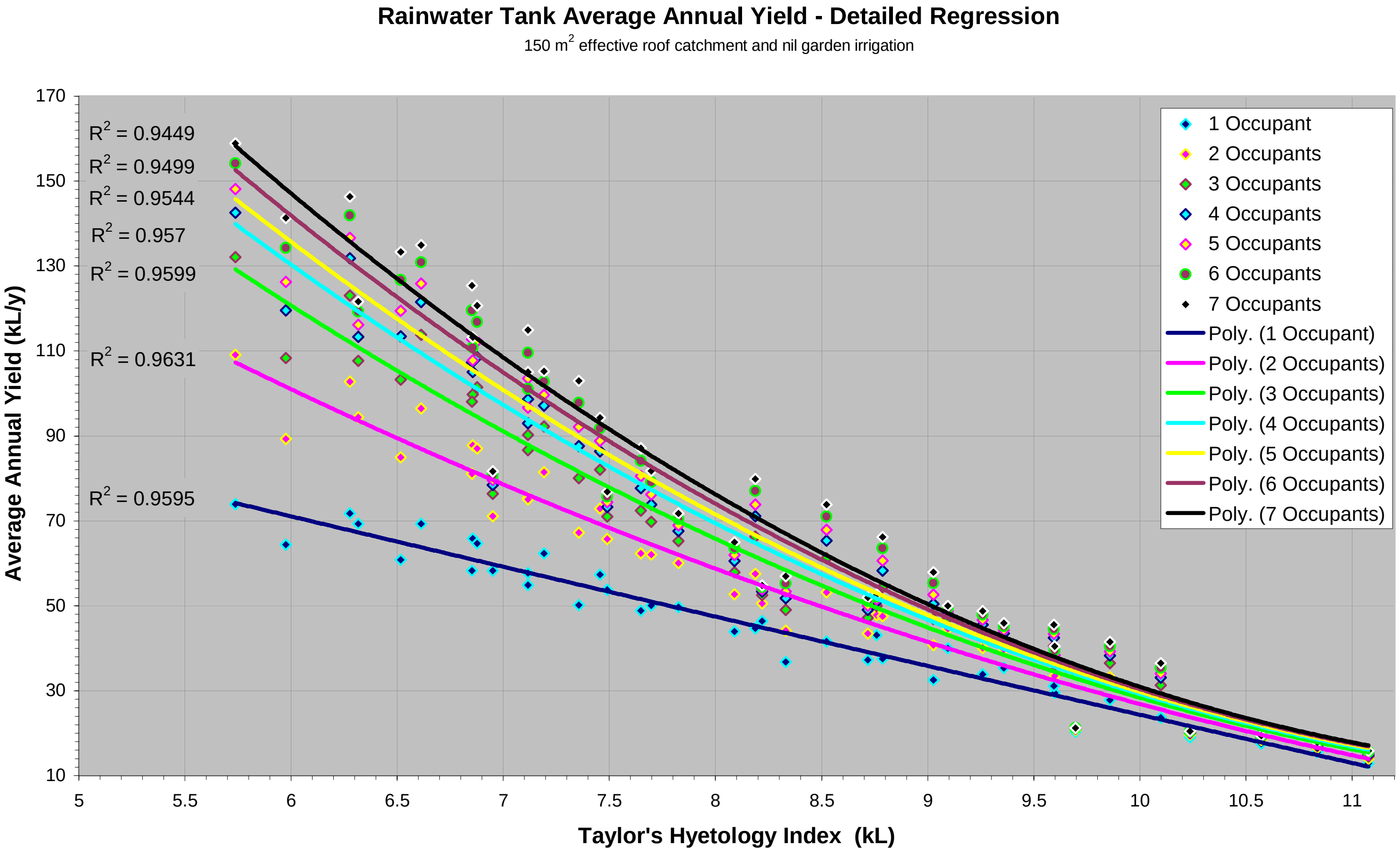
Appendix F

Hydrologic yield and water saving efficiency detailed regression charts

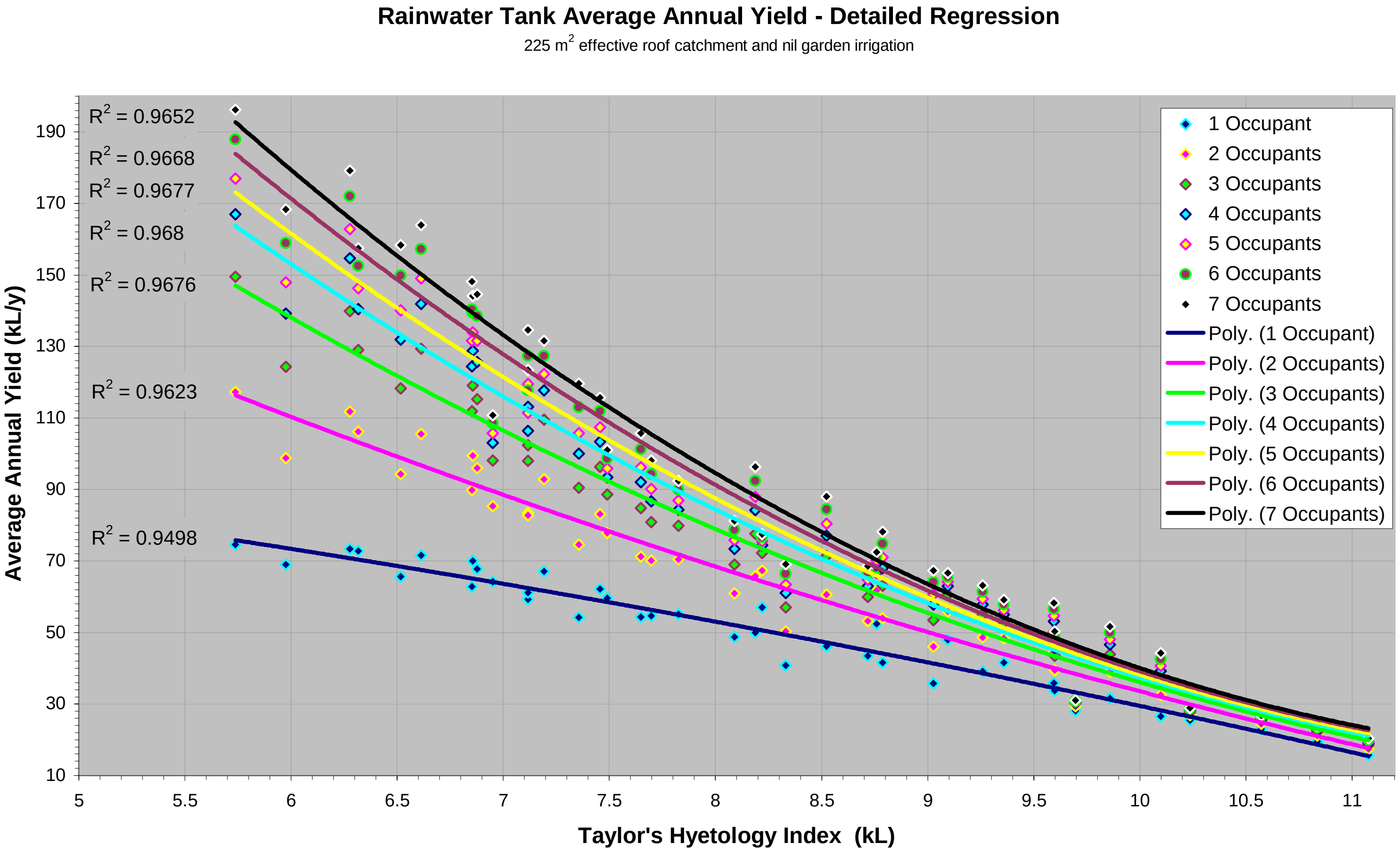
Contents



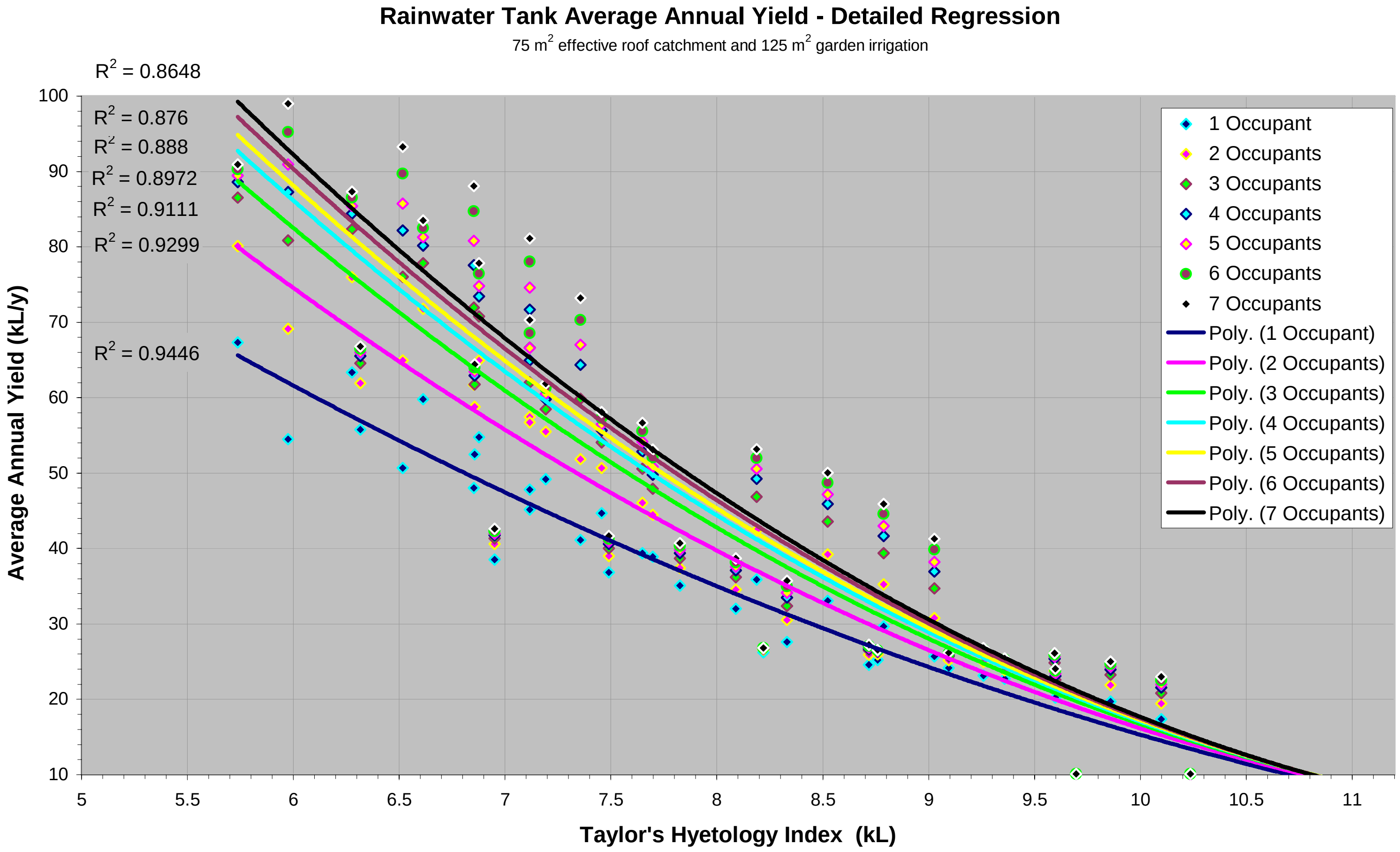
F. 1 **Hydrologic yield for 75 m^2 effective roof area and nil garden irrigation from THI and occupancy using polynomial regression**



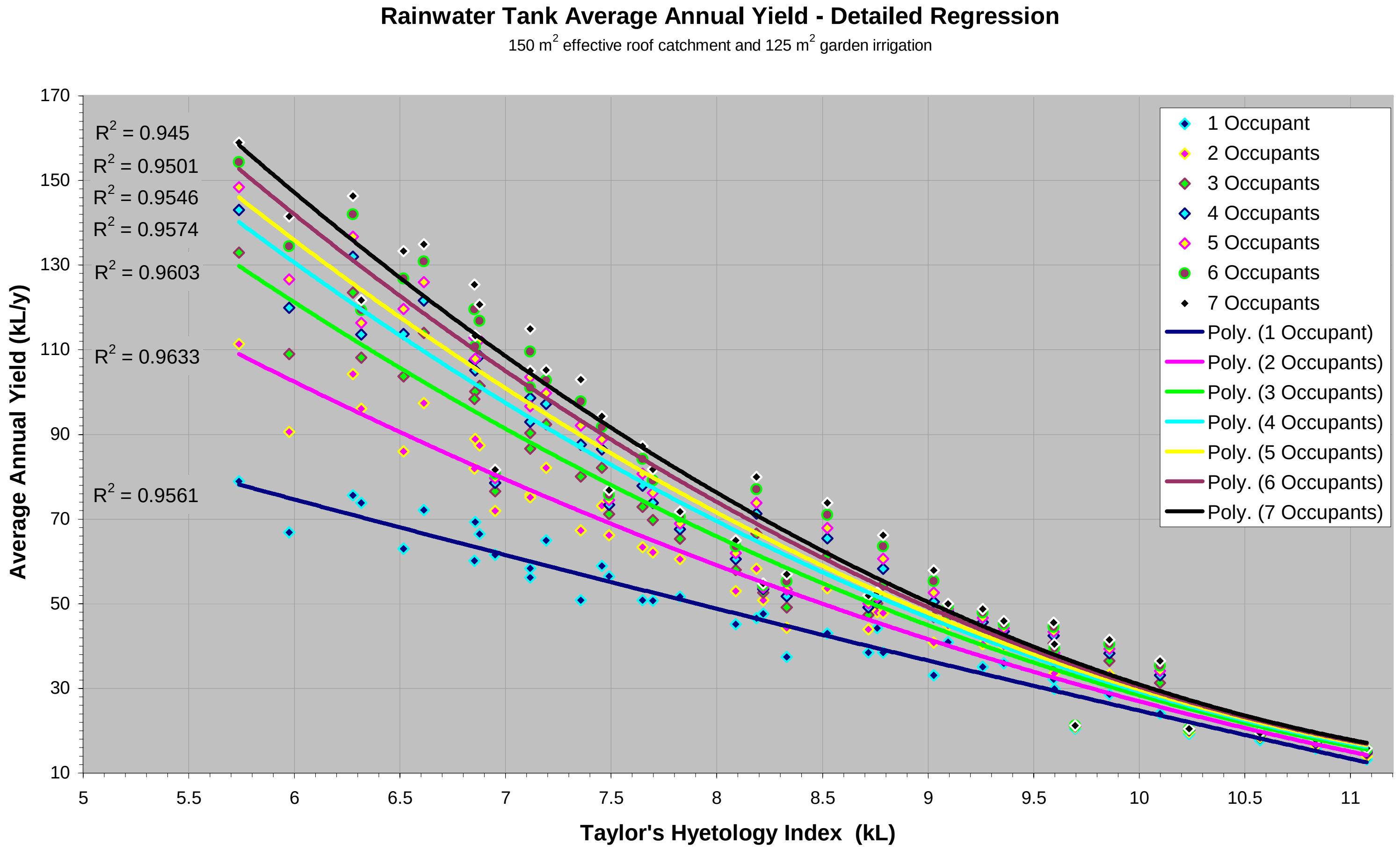
F. 2 **Hydrologic yield for 150 m^2 effective roof area and nil garden irrigation from THI and occupancy using polynomial regression**



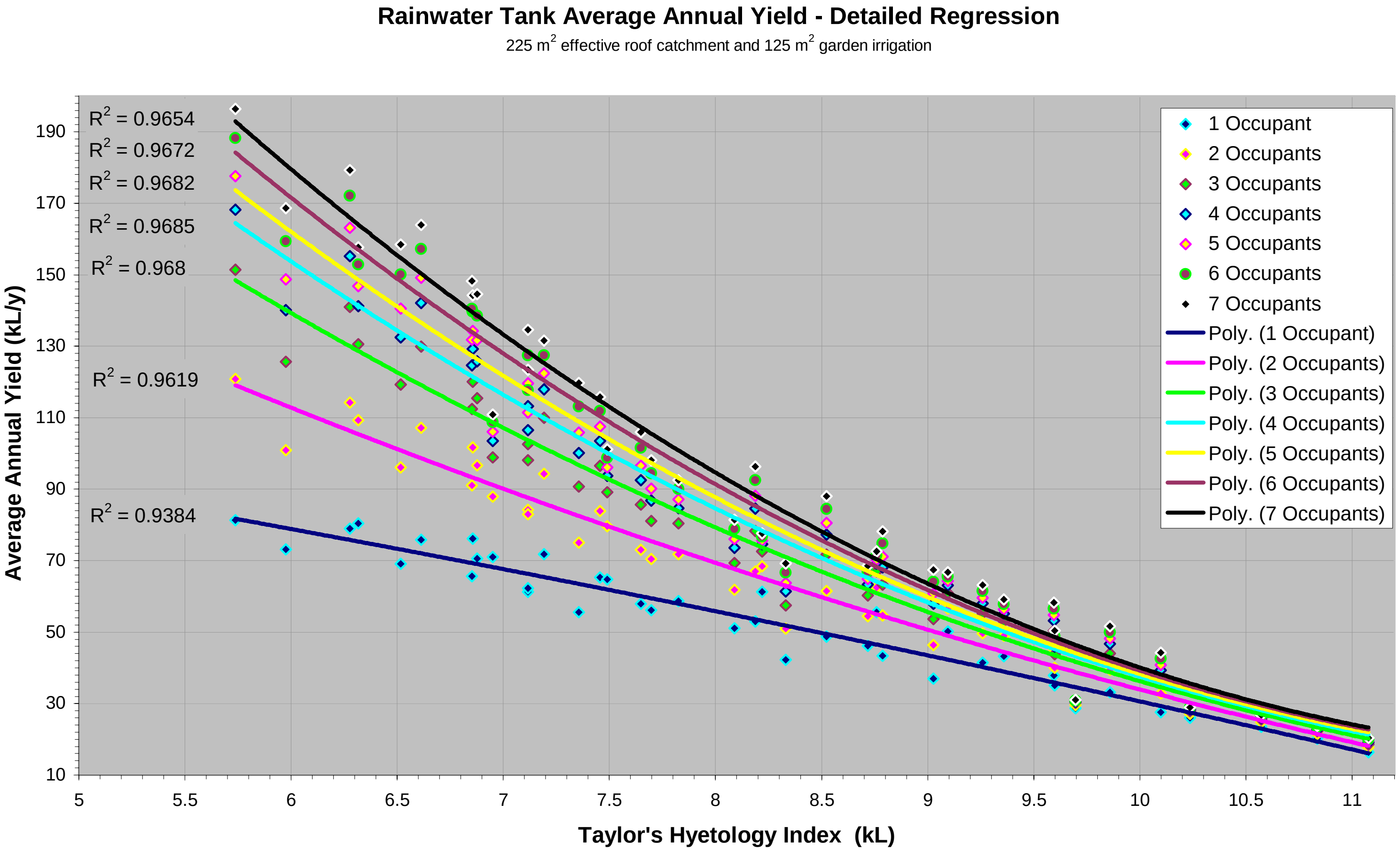
F. 3 **Hydrologic yield for 225 m^2 effective roof area and nil garden irrigation from THI and occupancy using polynomial regression**



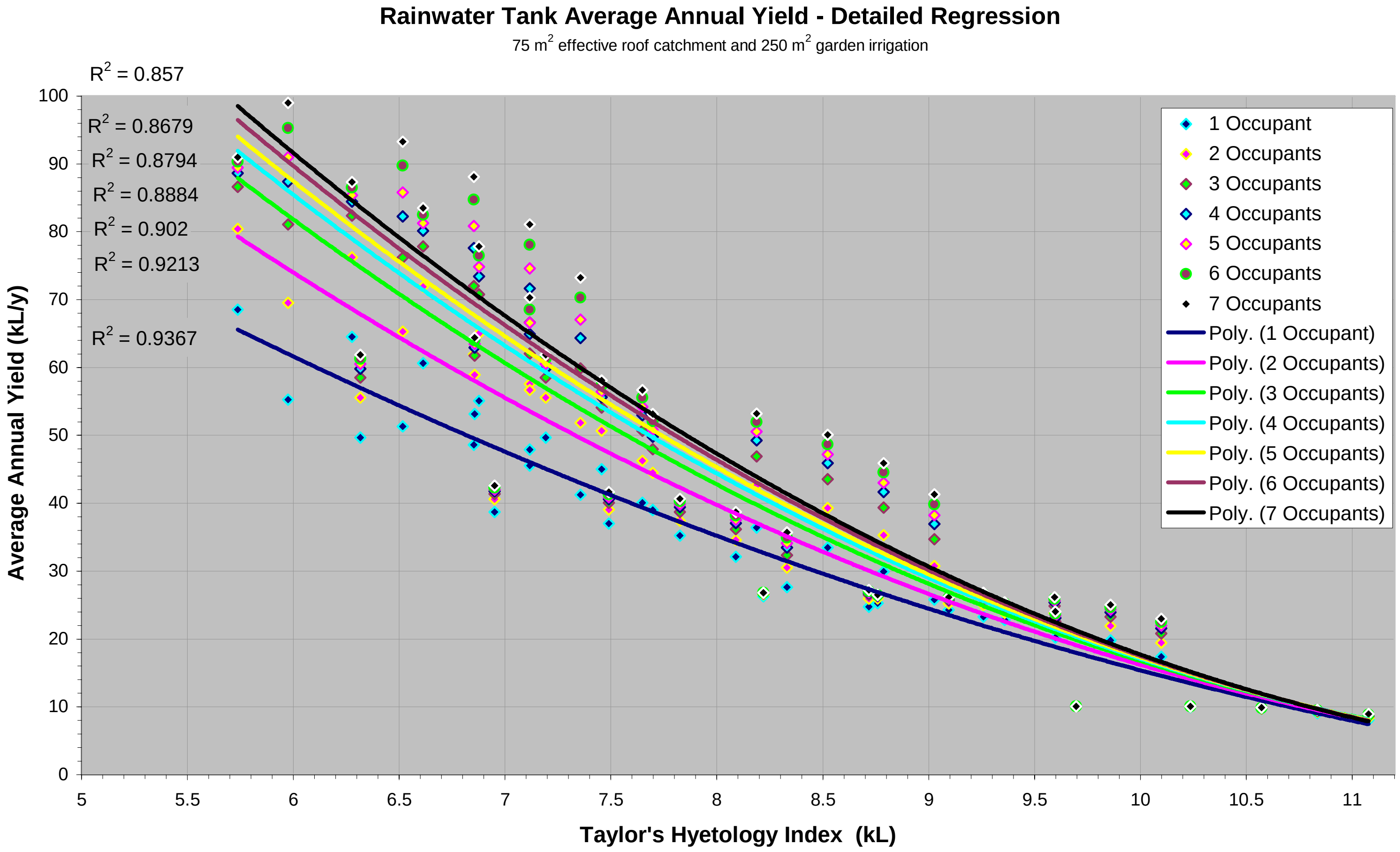
F. 4 **Hydrologic yield for 75 m² effective roof area and 125 m² garden irrigation area from THI and occupancy using polynomial regression**



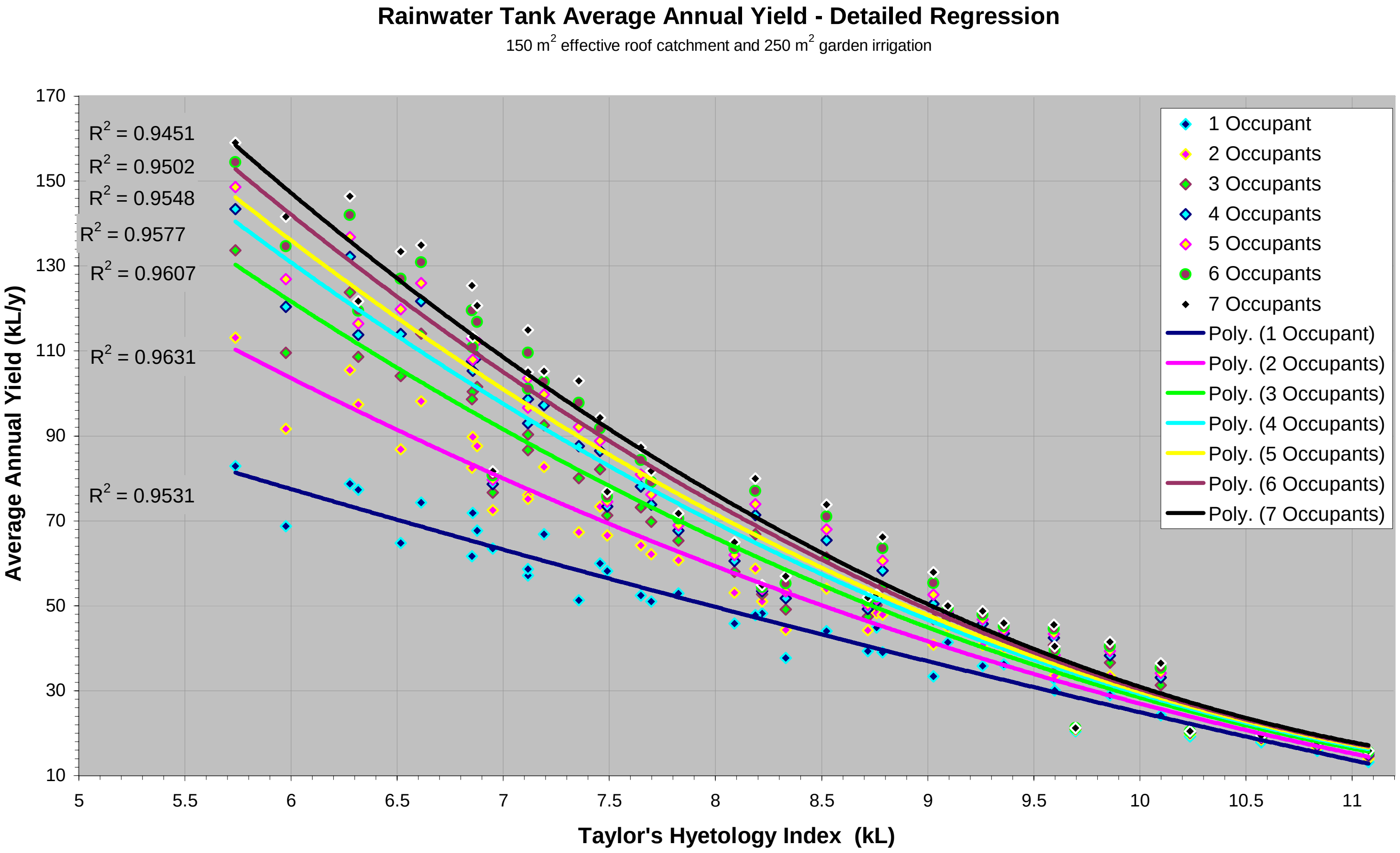
F. 5 Hydrologic yield for 150 m^2 effective roof area and 125 m^2 garden irrigation from THI and occupancy using polynomial regression



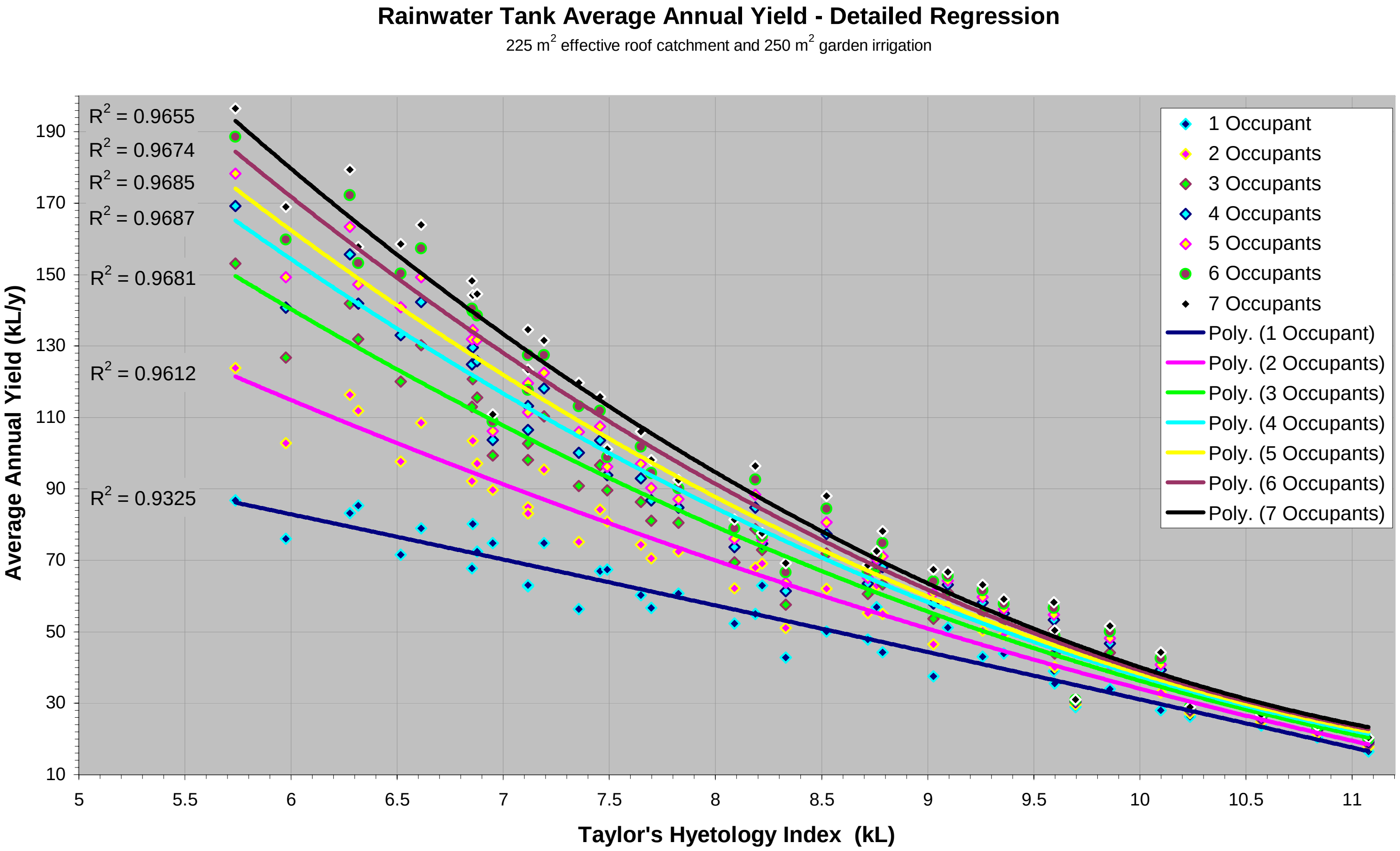
F. 6 Hydrologic yield for 225 m^2 effective roof area and 125 m^2 garden irrigation from THI and occupancy using polynomial regression



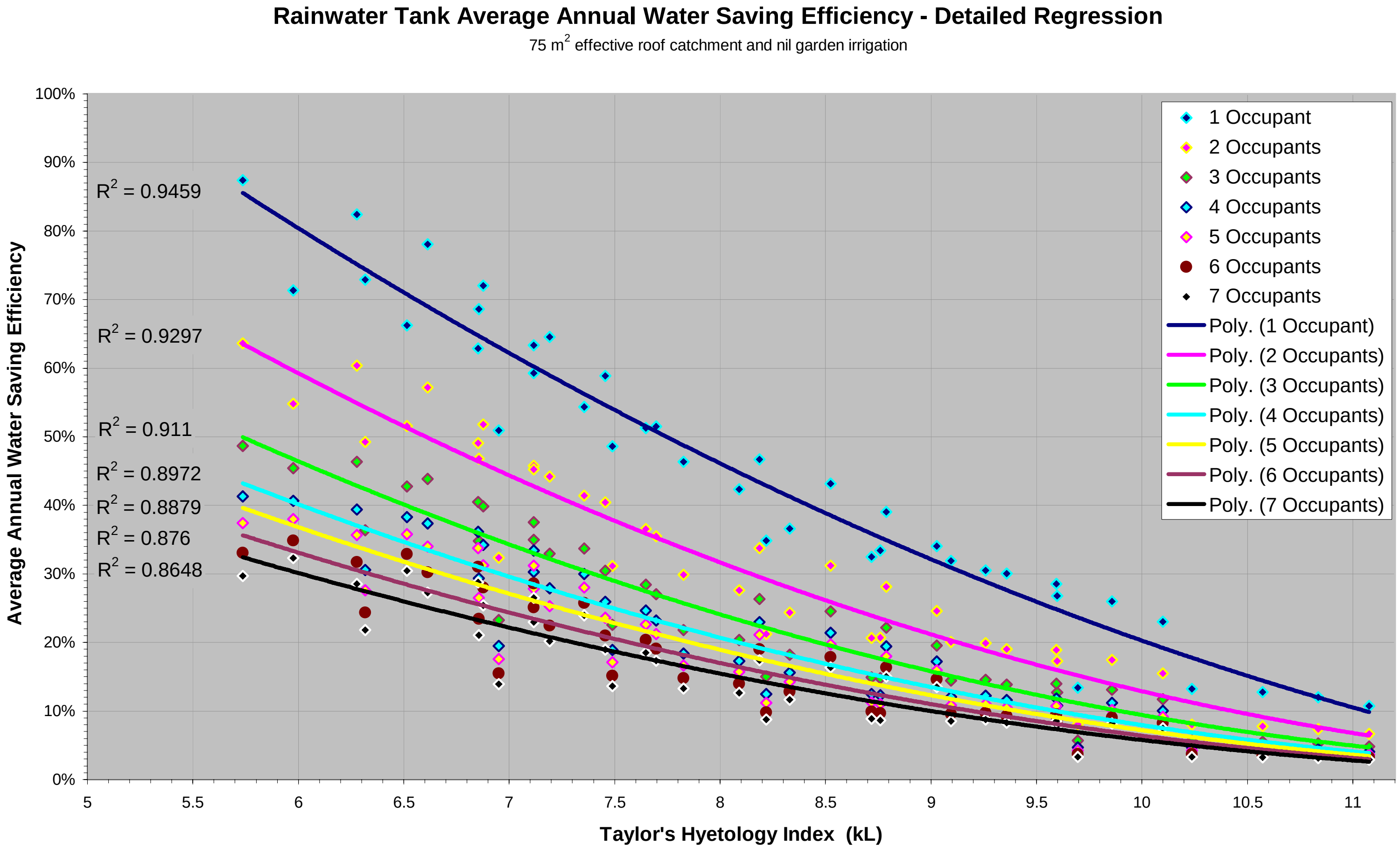
F. 7 Hydrologic yield for 75 m^2 effective roof area and 250 m^2 garden irrigation from THI and occupancy using polynomial regression



F. 8 Hydrologic yield for 150 m^2 effective roof area and 250 m^2 garden irrigation from THI and occupancy using polynomial regression



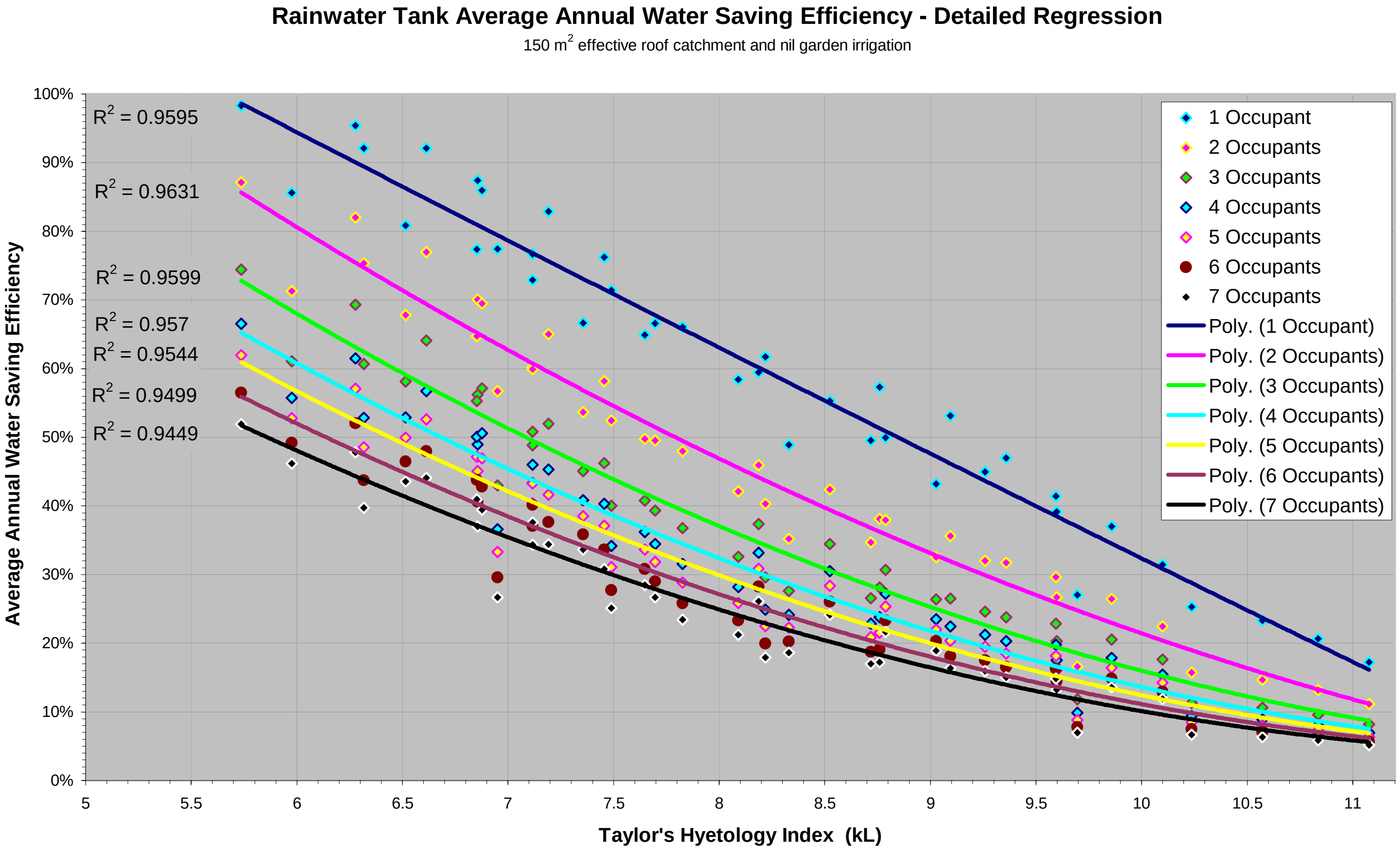
F. 9 Hydrologic yield for 225 m^2 effective roof area and 250 m^2 garden irrigation from THI and occupancy using polynomial regression



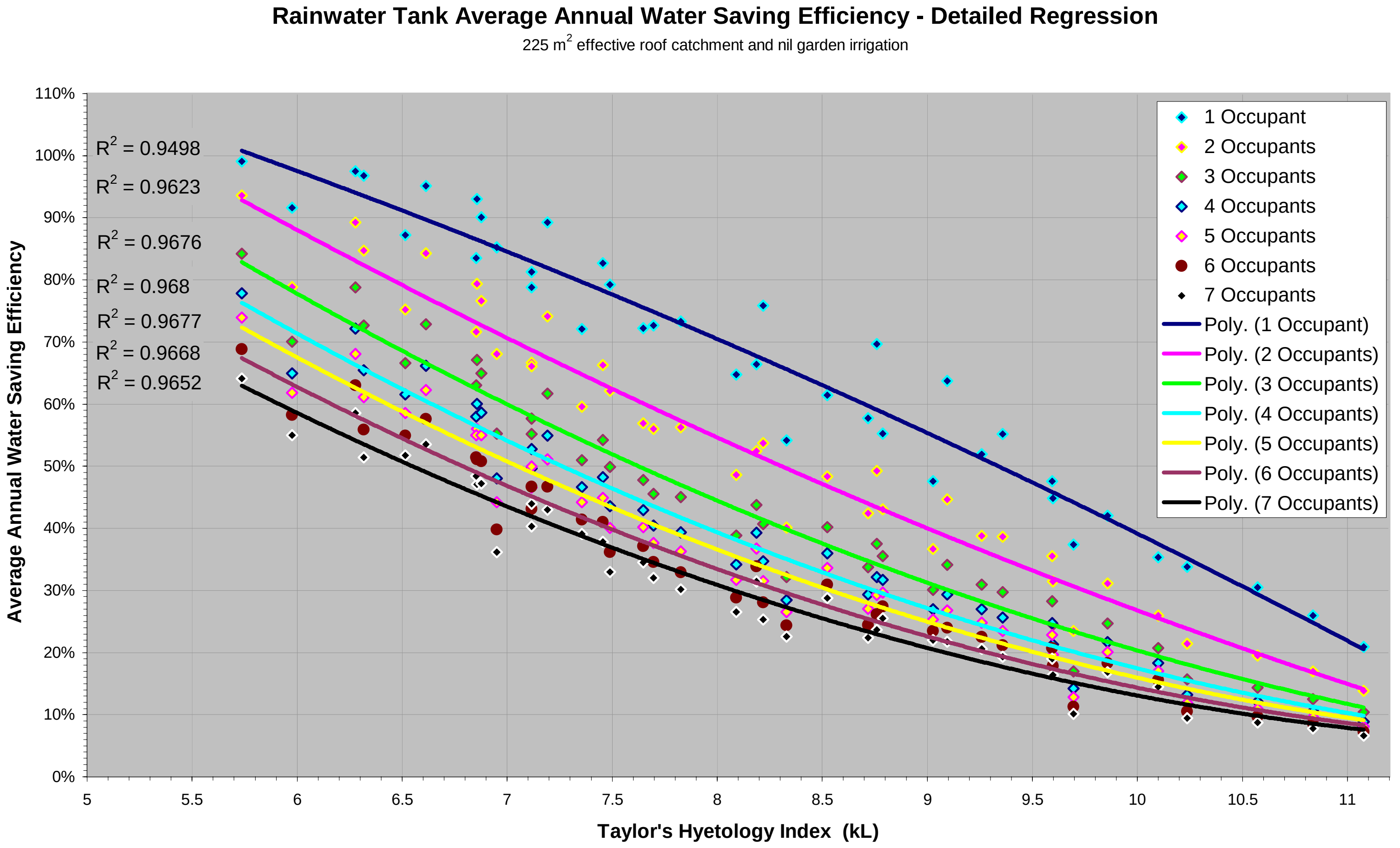
Rainwater Tank Average Annual Water Saving Efficiency - Detailed Regression

75 m² effective roof catchment and nil garden irrigation

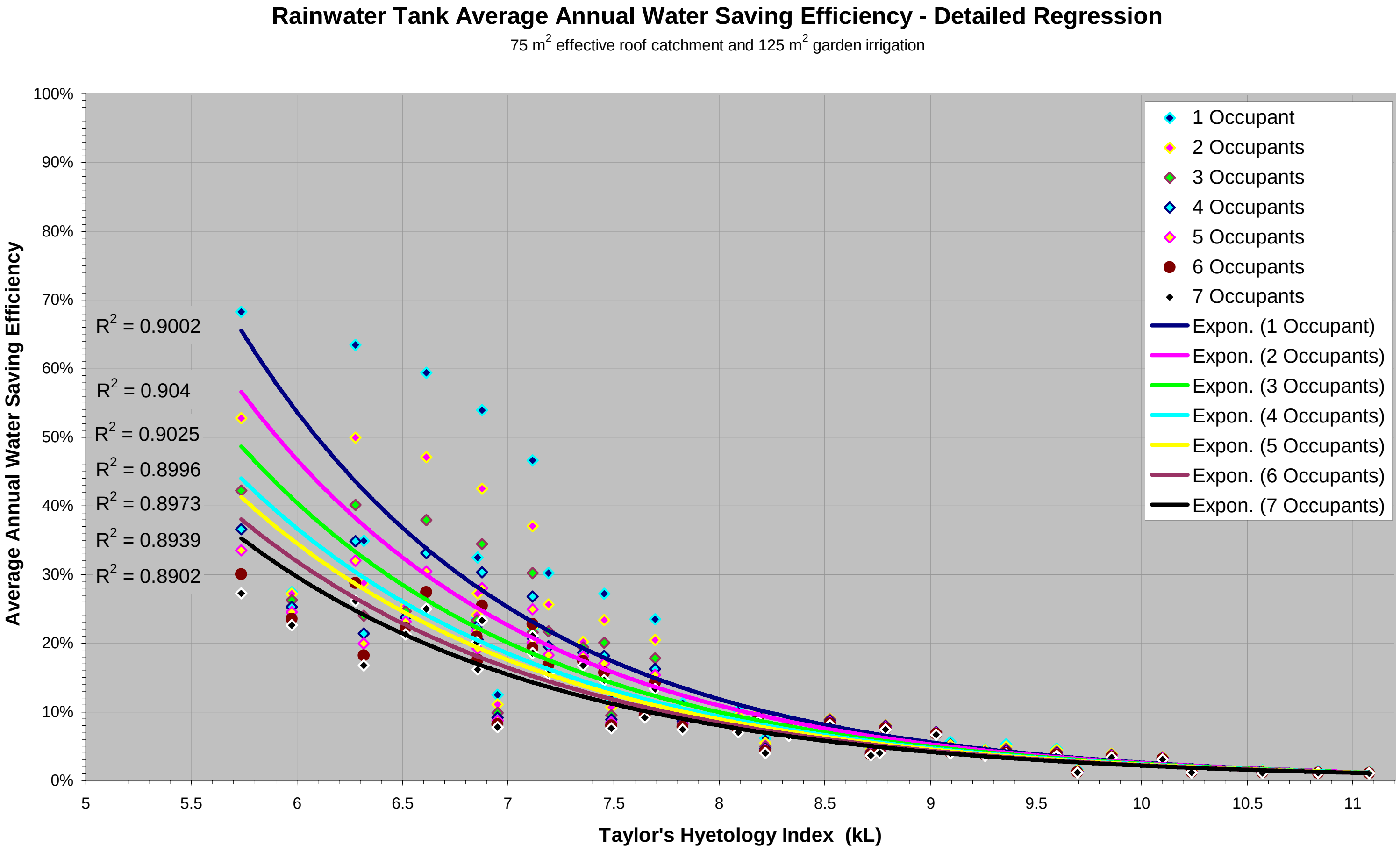
F. 10 Water saving efficiency for 75 m² effective roof area and nil garden irrigation from THI and occupancy using polynomial regression



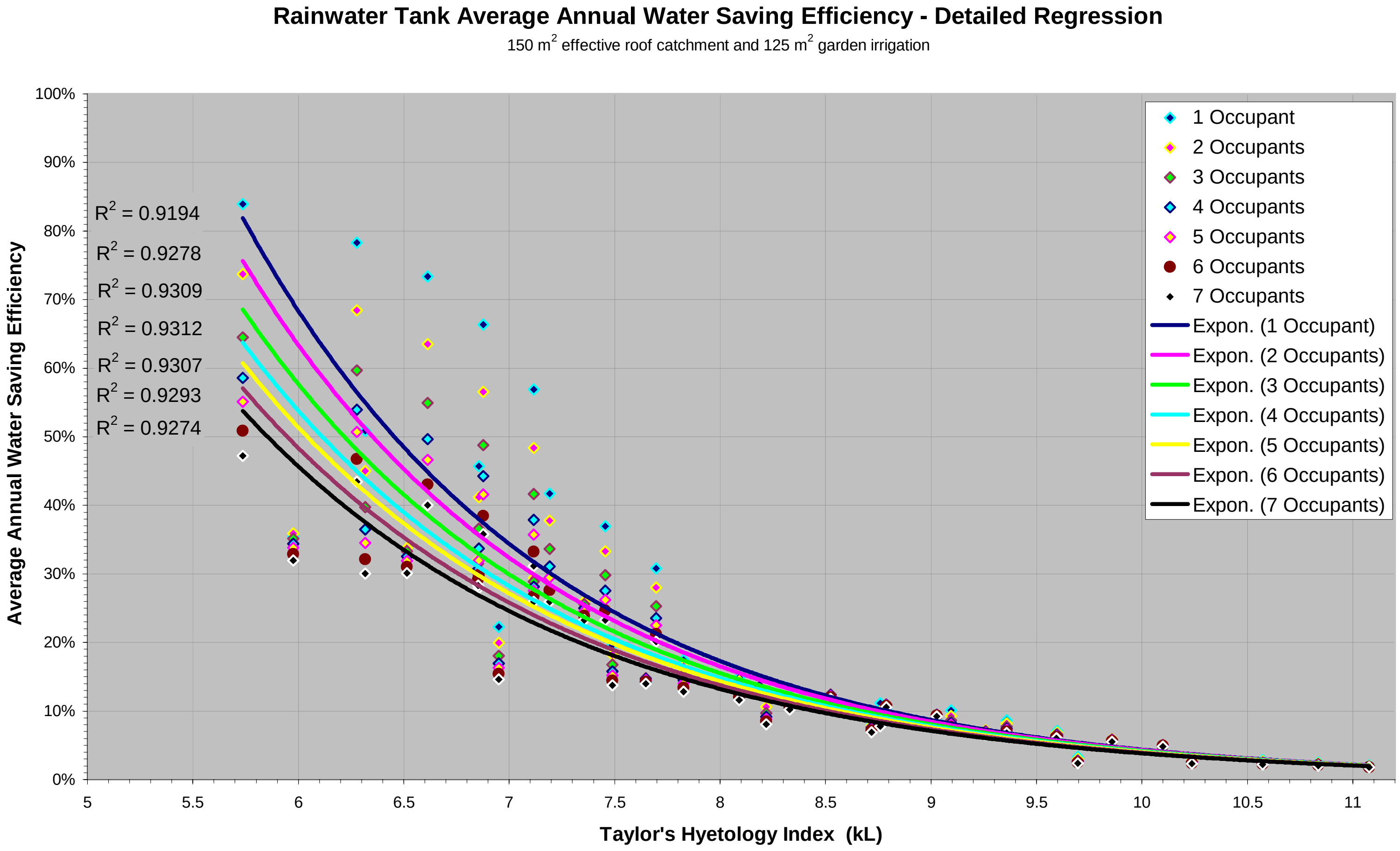
F. 11 Water saving efficiency for 150 m^2 effective roof area and nil garden irrigation from THI and occupancy using polynomial regression



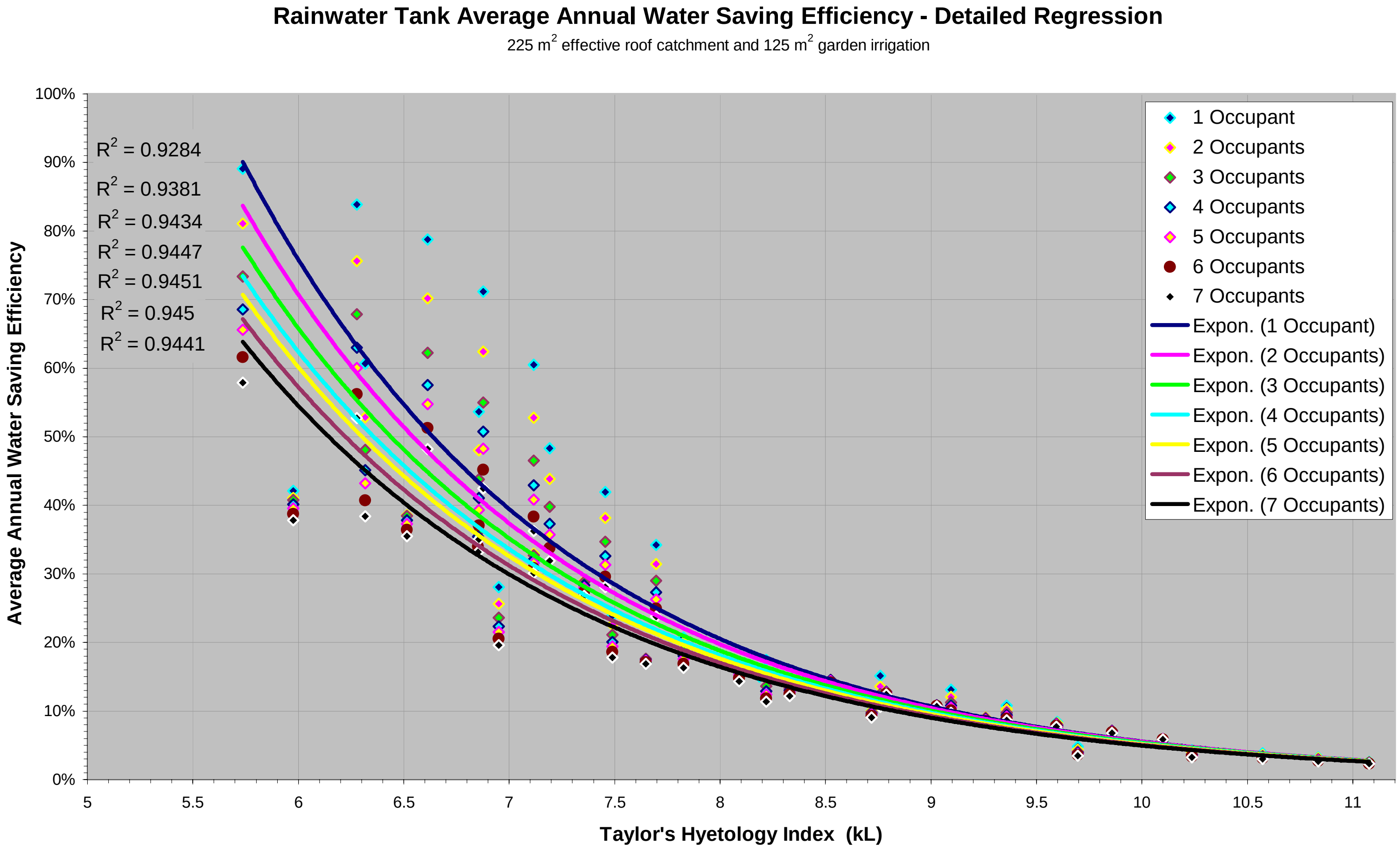
F. 12 Water saving efficiency for 225 m^2 effective roof area and nil garden irrigation from THI and occupancy using polynomial regression



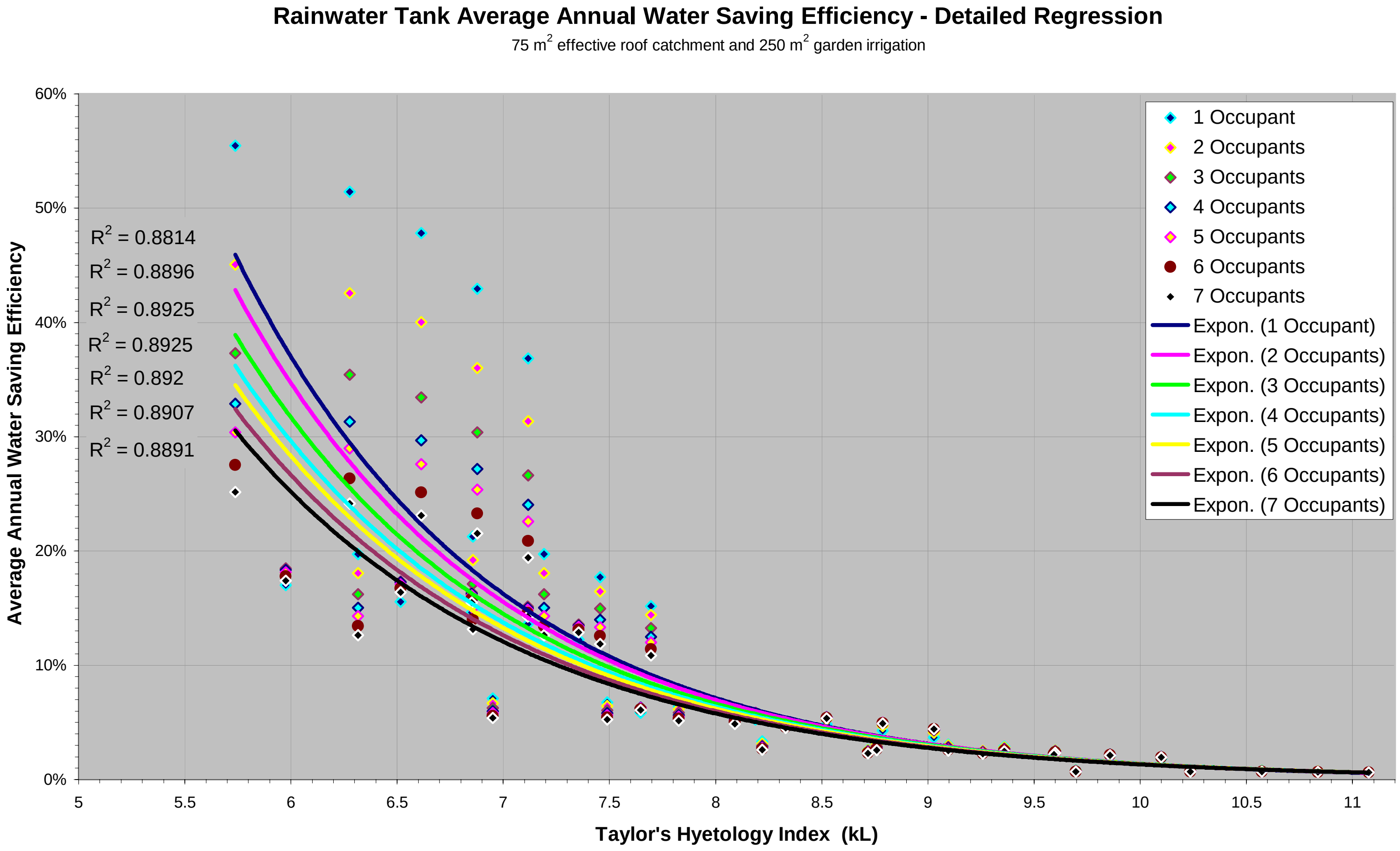
F. 13 **Water saving efficiency for 75 m^2 effective roof area and 125 m^2 garden irrigation area from THI and occupancy using exponential regression**



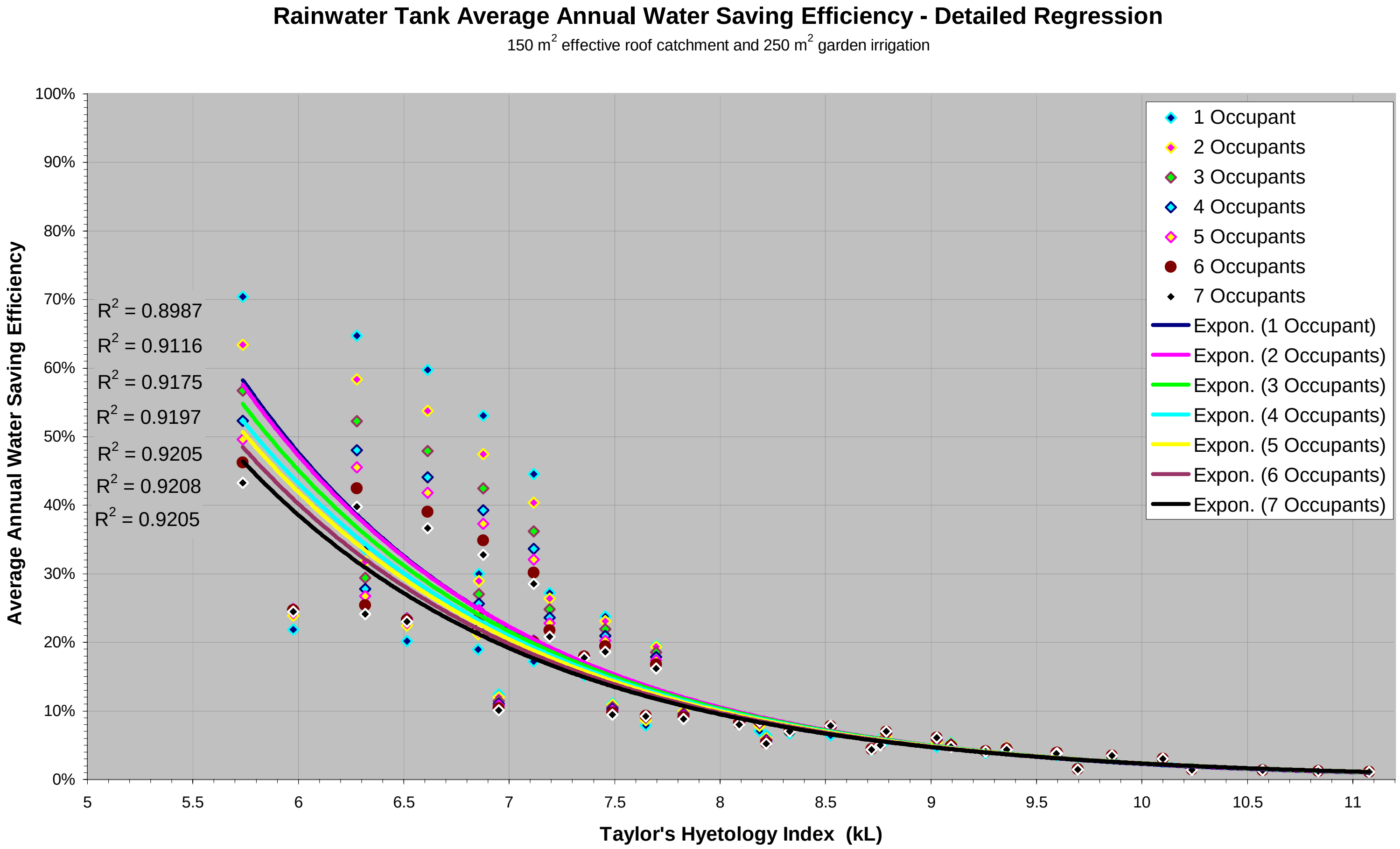
F. 14 **Water saving efficiency for 150 m^2 effective roof area and 125 m^2 garden irrigation area from THI and occupancy using exponential regression**



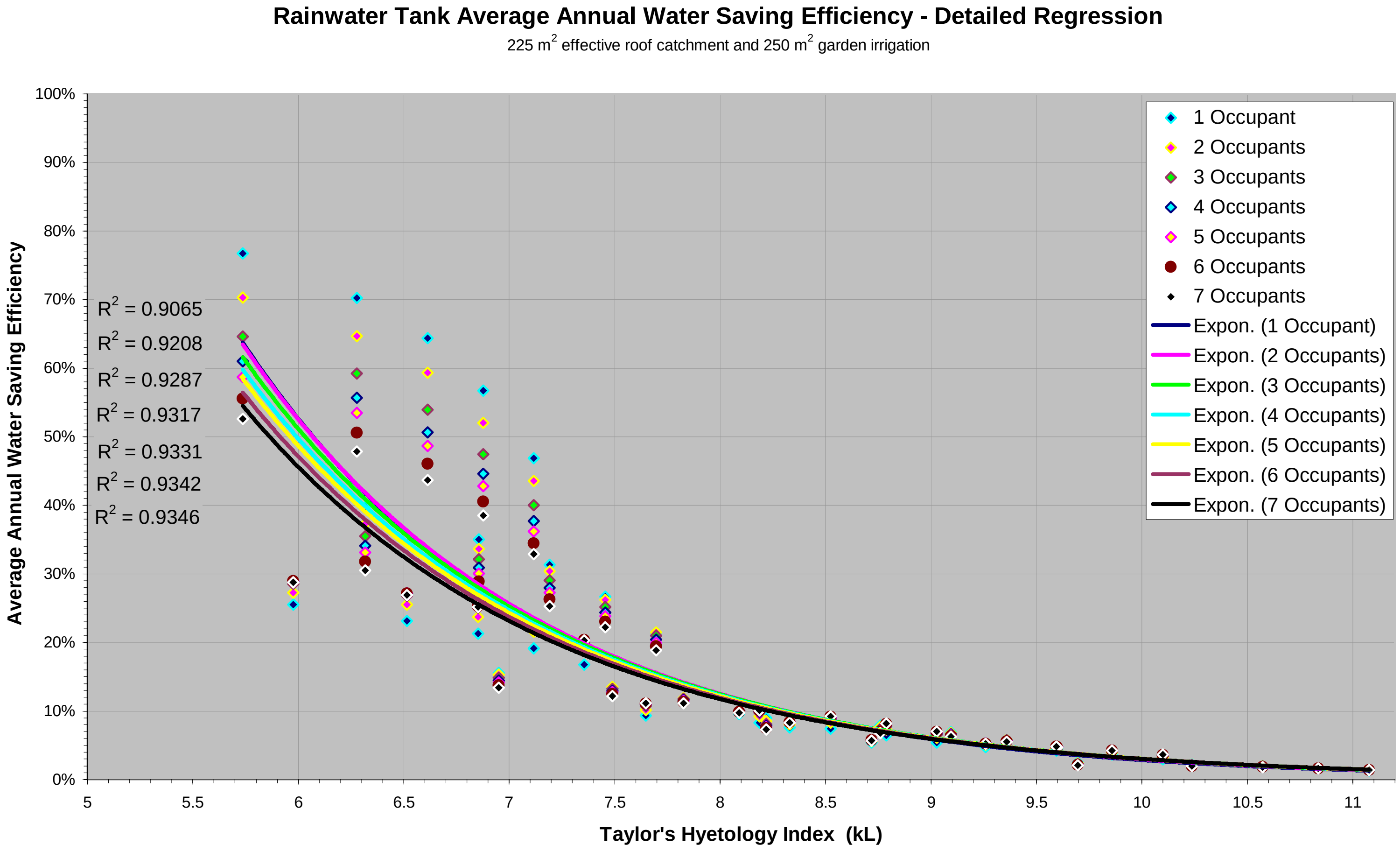
F. 15 Water saving efficiency for 225 m^2 effective roof area and 125 m^2 garden irrigation area from THI and occupancy using exponential regression



F. 16 **Water saving efficiency for 75 m^2 effective roof area and 250 m^2 garden irrigation area from THI and occupancy using exponential regression**



F. 17 Water saving efficiency for 150 m^2 effective roof area and 250 m^2 garden irrigation area from THI and occupancy using exponential regression



F. 18 Water saving efficiency for 225 m^2 effective roof area and 250 m^2 garden irrigation area from THI and occupancy using exponential regression