RAPID ESTIMATION OF RAINWATER YIELD THROUGHOUT AUSTRALIA AND REVIEW OF QUEENSLAND RAINWATER HARVESTING OPERATING POLICY

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Rapid estimation of national rainwater yield for low and high performance scenarios is derived using Taylor's Hyetal Index (THI). Stochastic representations of the modes of failure of rainwater harvesting (RWH) systems is the foundation of THI. THI holds a strong regression to RWH performance for 7,000 variations in the national residential built environment (r^2 = 0.96). A small subset of 34 variations is presented in this summary paper. THI is based on inspecting daily rainfall data from the Bureau of Meteorology, which enables rapid and accurate rainwater yield estimation at potentially any location throughout Australia. A review of the Queensland RWH mandate, using THI, has demonstrated many locations can achieve or are close to achieving their water saving targets. The worst performing region is South East Queensland, which is also an area of high population and municipal water demand. This region is also able to significantly exceed their water saving target, when adopting a RWH system beyond the mandate. Therefore, with changes to the mandate, Queensland could increase their renewable natural capital and societal and environmental benefit.

Introduction

The simplest and most universal example of extracting renewable natural capital is rainwater harvesting (RWH). In most urban residential settings, RWH is a low cost solution to supplementing stressed water resources by harvesting runoff that would otherwise contribute to our urban waste. By sourcing water at the point of supply and managing stormwater at the source, RWH reduces the scale of municipal reticulation and treatment infrastructure and consumption of non-renewable resources (Coombes 2002). As other alternate water supply options, such as desalination, fail to achieve these benefits and generate waste products, it is not surprising that a triple bottom line analysis shows the most cost effective means for increasing the security of urban water supplies is promoting rainwater systems (White 2009).

Water security is regarded as the challenge of the 21st century by many political and scientific institutions. The combined effects of water shortages, the paradigm shift to sustainable practices and climate change, are challenging how our water resources are managed. As such, society is restless and independently seeking security. Independence of water supply has turned the tide and is driving the revival of decentralised domestic RWH into our built environment (White 2009).

The strength of the revival is evident through the high rates of retrofitting in Queensland, after the rebate scheme was cancelled (White 2009). Governments have been contributing through legislation. Installation of RWH is now compulsory for new dwellings in Queensland (Qld. Gov. 2007) and most new and renovated dwellings in New South Wales (BASIX 2010). We are at the point of surging demand in the RWH technology lifecycle and we need to ensure the science is accurate.

Presently, a reliable unified national approach for rapidly estimating RWH performance at a regional resolution is missing. This is despite a clear relationship to rainfall and the availability of historic daily rainfall observations for 20,000 Bureau of Meteorology (BOM) stations in Australia. A unified national relationship to such an extensive resource will establish the technical foundation needed to ensure effective RWH systems are adopted and the societal and environmental benefits succeeded by this revival are amplified. This is the aim of the research.

Behavioural modelling of RWH

Behavioural modelling is the process of simulating the operation of a system at fine time steps within a large period. In the context of RWH, the time step is usually daily or smaller and the period can exceed 100 years. Many RWH behavioural models are currently in use (Mitchell et al. 2007 and Ward 2010). Aquacycle (Mitchell et al. 2001) was adopted by this research to establish RWH performance throughout Australia. The first phase of this research was to simulate over 7,000 domestic RWH installations to represent the variations in our national residential built environment. A subset of this data is presented herein.

The variation in simulation parameters included 17 sites to represent the seasonal rainfall zones of Australia (BOM 2005). BOM daily rainfall data from 1970 to 2009 was modelled at each site. The variation in effective roof area was represented by three values. The minimum value is 75 m^2, derived from an 85% runoff coefficient (Chapman & Salmon 1996) to the average Queensland connected roof area of 90 m^2 (White 2009). Also adopted was, a central value of 150 m^2 and an upper value of 225 m^2, derived from 90% runoff coefficient from the average total roof area of 250 m^2 (ABS 2010b). Variation in internal water use is represented by a relationship to household occupancy from 1 to 7 persons (Mitchell 2005) and where the average household occupancy of 2.5 persons (ABS 2010a) consumes 200 litres per day. This is the current domestic household target for South East Queensland. External water use varies from nil to the seasonal demand for maintaining a small (125 m^2) or large (250 m^2) garden bed. Tank volume varies between 3 kL and 14.5 kL to represent the minimum volume included in Queensland RWH mandate (Qld. Gov. 2007) and larger volumes typical in regional areas. Finally, four tank duties were modelled to represent the variation in fixtures supplied with rainwater, they include toilet and cold laundry only; total internal supply; toilet, cold laundry and garden irrigation; and total internal and external supply.

Stochastic RWH performance estimation

Jenkins (2007) developed a statistical relationship between RWH performance and rainfall seasonality. However, more recent work has proven this study to be less reliable (Taylor 2010b). Hanson et al. (2009) studied deriving RWH storage size to meet levels of supply reliability from daily rainfall statistics. However, RWH performance is approximately four times less sensitive to storage volume than catchment area (Taylor 2010a). Hanson adopted a unit catchment area which restricts the accuracy and relevance of this study. Developing a reliable stochastic relationship between the BOM daily rainfall data and the extensive behavioural modelling is the purpose of Taylor's Hyetal Index (THI) and is the second research phase. THI was established as part of BEng research (Taylor 2009) and allows rapid estimation of RWH performance. THI is derived through stochastic analysis of three modes of failure of a RWH system.

Failure can obviously occur from low rainfall over an extended period, where the system may empty and fail to meet demand. Also, failure can occur from high daily rainfall, where the system may be overwhelmed early in the rain event and will fail to intercept the remaining rainfall. Finally, failure can occur from continuous rainfall over many days or from separate rain events occurring within a small number of days. Here, the system may be overwhelmed not unlike excessive daily rainfall, but interception failure occurs after the first day and during the rain dominant period. The THI expression, incorporating the various failure modes, is presented in Equations 1 to 4.

$$THI = \frac{P_{cap}}{D_{total}}\left(1.95 - R_{pd} - R_{sp}\right) \tag{1}$$

where:

$$P_{cap} = \sum_{i=1}^{Dtotal} \min\left(P_i, \quad 19.0\right) \tag{2}$$

P_{cap} is the sum of daily precipitation (P_i) in a series of daily records of length D_{total}, but daily precipitation values are limited by a maximum threshold of 19.0 mm/d. This threshold is determined through minimising the regression sum of square error across the behavioural modelling results. The threshold suggests that precipitation over 19.0 mm/d is unlikely to affect rainwater yield and will contribute bias to the model if not removed. By summing daily values, the low rainfall failure mode is directly addressed. Also, the high rainfall failure mode is addressed by removing the portion of daily rainfall which has a high potential for system bypass, that is, rainfall above the daily threshold.

Dividing by the number of daily records converts the capped precipitation depth into a daily rate and allows comparison to any time series duration of annual multiples, which can be useful for analysis on temporal or spatial aspects. This increases the flexibility of THI and, as the remaining elements are unitless, provides the formula units of mm/d.

$$R_{pd} = \frac{D_{rain}}{D_{total}} \tag{3}$$

R_{pd} is the ratio of days with precipitation to total days in the time series. A large ratio indicates precipitation occurs frequently and failure by the continuity mode is more likely.

$$R_{sp} = \overline{\left(\frac{\max \sum_{i=1}^{6}\left(P_{mths(5-10)} \quad P_{mths(11,12,1-4)}\right)}{P_{annual}}\right)} \tag{4}$$

R_{sp} is the ratio of seasonal precipitation and is determined by dividing the maximum half year precipitation (May to October or November to April) by the annual precipitation for each year, then taking the mean ratio over the number of years in the time series. A large ratio indicates precipitation is seasonal and failure by continuity mode is more likely. R_{pd} and R_{sp} combine to quantify the potential of continuity mode failure from low (infrequent and uniformly distributed rainfall) through medium (infrequent seasonal rainfall or frequent uniformly distributed rainfall) to high (frequent and highly seasonal rainfall).

THI values for locations throughout Australia are shown in Table 1. Application of THI is demonstrated in a performance review of the Queensland RWH mandate, the final research phase.

Review of Queensland RWH mandate

For detached dwellings the principal requirements of the mandate are 5 kL tanks supplying toilets, cold laundry and one external tap and a connected roof area of the minimum of 100 m^2 or half the roof. Also established is a schedule of seven water saving targets ranging from 16 kL/hh/y in the Central West up to 70 kL/hh/y in the South East Corner. If RWH fails to achieve these yield targets then greywater recycling systems may be required.

Rainwater yield will be estimated using THI and two scenarios which represent the lower and upper performance that can be expected when following the mandate. The lower performance scenario consists of a 5 kL tank, 75 m^2 effective catchment, 2.5 occupants, toilet and laundry supply, and failure to use rainwater for external use. The upper performance scenario adopts a 150 m^2 effective catchment and external supply for irrigating a 125 m^2 garden bed, all other parameters are identical. National performance under these scenarios is shown in Figures 1 and 2, respectively.

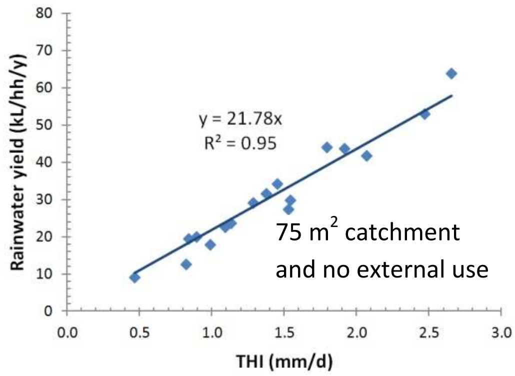
An ultimate performance scenario is also included to demonstrate a realistic performance ceiling. This scenario adopts a 225 m^2 effective catchment and supplies rainwater to all internal and external fixtures. It should be noted, further performance would be achieved if the tank volume is also increased, however, tanks larger than 5 kL are rarely seen in our most populated residential areas. Refer to Figure 3 to compare the three scenarios with the schedule water saving targets.

Results

Table 1. THI values for locations throughout Australia

Site	P_{cap}	R_{pd}	R_{sp}	THI	Site	P_{cap}	R_{pd}	R_{sp}	THI
Birdsville*	0.39	0.09	0.67	**0.47**	Longreach	0.79	0.15	0.75	**0.83**
Bourke NSW*	0.82	0.18	0.56	**0.99**	Mackay	2.41	0.45	0.80	**1.67**
Bowen	1.31	0.25	0.84	**1.12**	Maryborough	2.05	0.41	0.68	**1.77**
Brisbane*	2.09	0.37	0.66	**1.91**	Melbourne*	1.54	0.46	0.50	**1.53**
Bundaberg	1.82	0.38	0.69	**1.60**	Mildura*	0.69	0.22	0.55	**0.82**
Cairns*	3.11	0.51	0.87	**1.79**	Moranbah	1.14	0.21	0.76	**1.12**
Caloundra*	2.76	0.43	0.62	**2.46**	Mount Isa*	0.93	0.17	0.88	**0.84**
Canberra*	1.41	0.32	0.54	**1.54**	Mungindi	1.04	0.18	0.63	**1.20**
Cardwell	3.10	0.52	0.86	**1.78**	Perth*	1.88	0.34	0.84	**1.45**
Charleville*	1.00	0.20	0.65	**1.09**	Port Lincoln*	1.46	0.42	0.76	**1.13**
Charters Tow.	1.31	0.23	0.82	**1.17**	Rockhampt.*	1.51	0.32	0.72	**1.37**
Chillagoe	1.67	0.22	0.94	**1.32**	Strahan*	4.22	0.70	0.62	**2.65**
Cooktown	2.85	0.49	0.89	**1.62**	Sydney*	2.09	0.40	0.56	**2.06**
Coolangatta	2.75	0.47	0.66	**2.26**	Taroom	1.31	0.23	0.66	**1.38**
Croydon	1.39	0.20	0.95	**1.12**	Toowoomba	1.88	0.36	0.66	**1.74**
Emerald	1.23	0.24	0.70	**1.25**	Townsville*	1.67	0.30	0.88	**1.28**
Geraldton*	1.02	0.25	0.83	**0.89**	Urangan	2.05	0.44	0.64	**1.78**
Gladstone	1.56	0.32	0.71	**1.43**	Weipa	3.14	0.40	0.97	**1.83**
Ipswich	1.69	0.33	0.68	**1.58**	Wondai	1.56	0.29	0.66	**1.56**

Note: * denotes the 17 sites used for national regression of THI coefficients and constants.



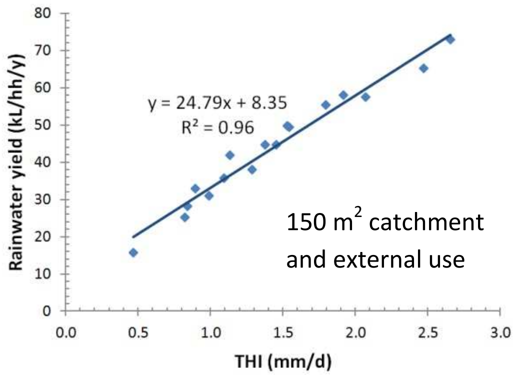


Figure 1. National rainwater yield for the lower performance scenario

Figure 2. National rainwater yield for the upper performance scenario

Lower rainwater yield = 21.8 × THI

Upper rainwater yield = 25.8 × THI + 8.35

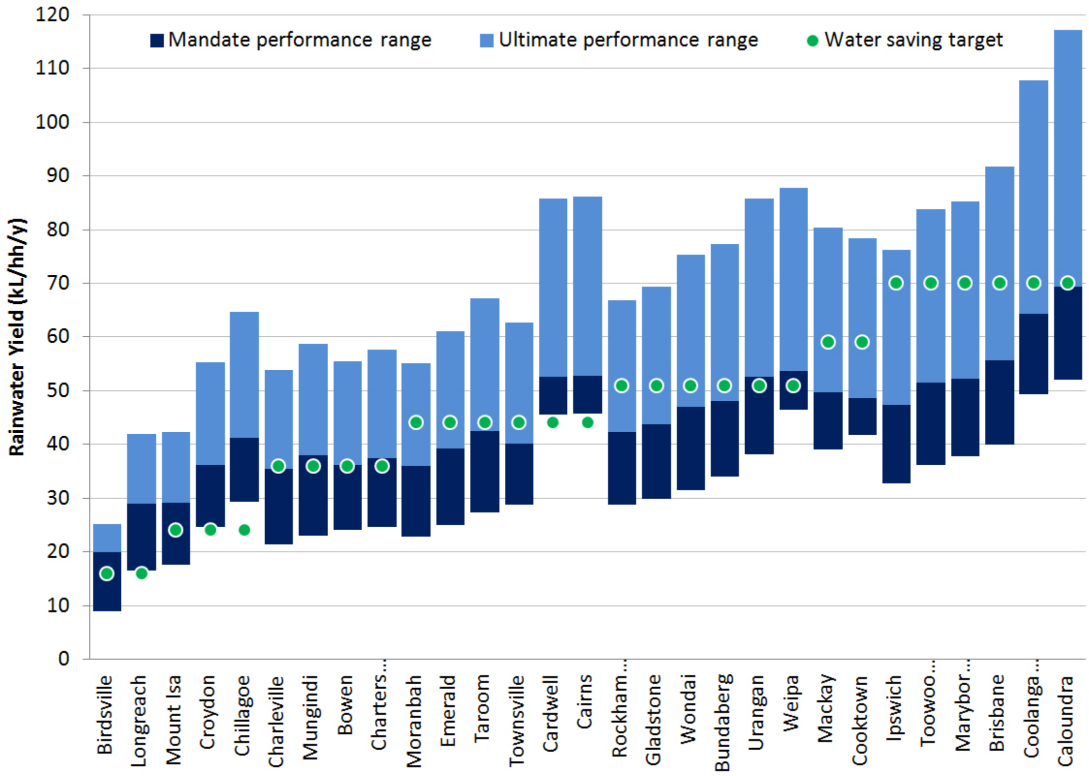


Figure 3. Queensland ultimate RWH performance, mandate performance (bound by lower and upper scenarios) and water saving targets.

Conclusions

A stochastic method for rapid estimation of rainwater yield has been developed in Taylor's Hyetal Index (THI). THI has demonstrated accurate prediction (r^2 = 0.96) of rainwater yield from a sample of over 7,000 variations in the national residential built environment. By using daily rainfall data from the Bureau of Meteorology, THI can potentially derive rainwater yield at any national location.

A review of the Queensland RWH mandate, using THI, has demonstrated many locations can achieve or are close to achieving their water saving target. The worst performing region is South East

Queensland, which is also an area of high population and municipal demand. Fortunately, when adopting a RWH system beyond the mandate, this region is able to significantly exceed their water saving target. Therefore, with changes to the mandate, Queensland could increase their renewable natural capital, reduce non-renewable resource consumption and secure their urban water supply, thereby increasing societal and environmental capital through low cost RWH technology.

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