APPROACHING WATER SENSITIVE CITIES WITH ADAPTIVE RAINWATER DIVERSION

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ABSTRACT

Total water cycle management (TWCM) discussion mostly limits the role of residential rainwater harvesting to providing an alternate water supply to a fraction of fit-for-purpose end uses. However, with operational improvements, greater outcomes can be achieved. By increasing the portion of roof area connected and developing adaptive rainwater diversion (ARD), reliable stormwater management outcomes can also be achieved. ARD controls tank drawdown by adapting to changes in dwelling consumption and rainfall, thus allowing the available storage to mimic the pre-urbanised catchment storage recovery. The ARD approach has the basis that mains water savings can be achieved in two ways: 1) Rainwater supply - where the rainwater harvest is used directly to reduce mains consumption of that dwelling; and 2) Rainwater diversion - where rainwater is diverted from the dwelling. This does not directly reduce mains consumption of the dwelling but produces a water resource that is used by others to reduce mains consumption. In this way, total rainwater yield and mains water savings is the sum of rainwater supply and diversion. This research investigates rainwater supply, rainwater diversion, runoff volume and runoff flow frequency for South East Queensland. Results show, the average sized detached dwelling when fitted with a 5 kL tank and ARD system is compliant with the mandated water saving targets and the Queensland Best Practices Environmental Management Guidelines for stormwater flow frequency management.

It is recommended that rainwater is diverted into the existing stormwater system where reuse facilities exist. Otherwise, discharging into the sewer, has the potential to reduce sewer fouling and increase the substitution of mains supply with treated effluent. This improves sewerage reticulation by adding a secondary purpose and, by using existing infrastructure, removes many barriers for retrofitting TWCM and water sensitive urban design (WSUD). Also, as ARD brings adaptive and multifunctional infrastructure into our urban design, we begin to develop water sensitive cities. The outcomes of this research are most promising to established and future planned high density residential suburbia, where TWCM policy and WSUD is chiefly needed.

INTRODUCTION

Water sensitive cities must have adaptive and multifunctional infrastructure, among many other capacities. Achieving this, is the ultimate goal of water sensitive urban design (WSUD). WSUD focuses on overturning our culture of misuse and waste of water resources by recognising the life-sustaining qualities of water in the design of our urban environment (Water by Design 2009). WSUD applies to all elements of our built environment from the urban core to rural living and extends into rural production. Incorporated are aspects of water conservation in addition to the management of stormwater flow frequency, waterway stability and stormwater quality.

Rainwater harvesting at either the allotment or cluster scale contributes to WSUD in all elements of the built environment in the following ways:

- Contributes to water conservation - With first flush devices fitted, rainwater is fit-for-purpose to substitute mains water for all non-potable end uses (Qld DIP 2007), which can constitute more than 80% of residential consumption (Willis et al. 2011);
- Contributes to stormwater quality management - Storing water or running water through a rainwater tank can reduce pollutant loading; and

- Contributes to waterway stability management - The airspace above the obvert of the overflow outlet provides storage that can fill during excessive rain events. This occurs when the inflow rate exceeds the outflow rate. The result is, attenuation of the peak discharge.

Rainwater harvesting is however, unreliable at managing stormwater flow frequency. Flow frequency management is important for urban catchments. The introduction of highly efficient stormwater delivery systems and smooth impervious areas, in the way of roads, rooves and driveways, has resulted in runoff occurring from smaller and more frequent rain events. These repeated impacts are degrading our urban creeks and streams in a process referred to as the urban stream syndrome (Meyer et al. 2005; Walsh et al. 2005a; Walsh et al. 2005b).

Reliable flow frequency management is achieved when adequate rainwater storage capacity is available prior to a rain event. Usually, the daily consumption of rainwater is too low and rainwater storage is insufficient. Also, there are many reasons why rainwater consumption from any dwelling may decrease, such as reduced irrigation in winter or a period of vacancy due to work, holiday or a change in tenants. This is evident in the variability of rainwater yield reported by recent studies (Beal et al. 2010). With diminishing consumption and performance variability, the rainwater harvesting contribution to flow frequency management is not assured and should be considered in WSUD cautiously.

Periodic diversion of rainwater can overcome this limitation. This diversion aims to control the tank drawdown rate, or critical period, and provide sufficient storage for reliable flow frequency management. Ideally, rainwater should be diverted to a system that can treat and return the water to municipal supplies. In this case, the diversion should be slow enough not to overwhelm the receiving system. This is a desirable outcome, as the diversion could occur under gravity flow, thereby allowing rainwater to be used without the high energy costs associated with small decentralised pressure pumps.

(Brodie 2009) introduces the concept of trickle diversion from communal rainwater tanks to achieve flood discharge reduction, stormwater flow moderation and to overcome the management and ownership constraints of individual residential tanks. In this concept, the diverted rainwater is returned to the municipal water supply using a stormwater harvesting scheme. In many situations, the barriers for retrofitting communal rainwater tanks and stormwater harvesting schemes are too great. Thus, an alternative is needed that promotes multifunction of existing infrastructure at the household level.

With treatment at the household level, rainwater diversion would need to adapt to changes in rainfall and consumption to ensure optimum performance. Otherwise, when rainwater consumption returns to normal or when rainfall reduces the system will drain too quickly, and the reliability of rainwater supply will be compromised. To be adaptive, the diversion would be controlled by an electronic device which monitors the rainwater tank. This device would divert rainwater, via a trickle outlet, under the right conditions.

It is therefore hypothesised that introducing a system of adaptive rainwater diversion (ARD) will extend the role of rainwater harvesting to runoff flow frequency management, while simultaneously achieving water conservation and providing adaptive and multifunctional infrastructure, as needed to develop water sensitive cities. The objectives of this study are:

- Assess the dual performance (water conservation and runoff frequency management) of rainwater harvesting, with and without ARD, and while configured in accordance with the

Queensland rainwater harvesting operating policy (Qld DIP 2007) for detached dwelling in South East Queensland (SEQ);

- Assess the dual performance of rainwater harvesting, with and without ARD, and while optimised for dual operation;
- Assess the difference in rainwater supplied to the dwelling resulting from introducing ARD;
- Assess the response of the ARD system to changes in consumption and rainfall.

METHODOLOGY

To achieve the study objectives many scenarios were simulated using MUSIC and Excel. Table 1 defines the parameter values and purpose of each scenarios.

Table 1 Modelling scenarios

Parameter	Adopted values	Comments
Connected roof area[¤]	100 m^2	Mandate minimum - for assessing mandate performance
	150 m^2	Intermediate value - for assessing intermediate performance
	200 m^2	Practical maximum value - for assessing ultimate performance
Rainfall[€]	Below long term average	Reduced rainfall scenario - for assessing Brisbane performance
	Equivalent to long term average	Average rainfall scenario - for assessing Caloundra performance
	Above long term average	Elevated rainfall scenario - for assessing Gold Coast performance
Consumption[¥]	184 L/pc/d supplying all non-potable fittings[µ]	100% occupancy or 2.5 persons - for assessing ultimate performance - annual consumption from rainwater connected fittings **134 kL/dwelling/yr**
	184 L/pc/d supplying the minimum fittings[§]	100% occupancy or 2.5 persons - for assessing mandate performance - annual consumption from rainwater connected fittings **84 kL/dwelling/yr**
	92 L/pc/d supplying the minimum fittings[§]	50% occupancy or one full time occupant - for assessing diminishing consumption - annual consumption from rainwater connected fittings **42 kL/dwelling/yr**
	37 L/pc/d supplying the minimum fittings[§]	20 % occupancy or one intermittent occupant - for assessing diminishing consumption - annual consumption from rainwater connected fittings **16 kL/dwelling/yr**
	4 L/pc/d	Vacant dwelling - for assessing diminishing consumption - annual consumption from rainwater connected fittings **2 kL/dwelling/yr**
Rainwater system	5 kL tank only	Mandate minimum - for assessing conventional rainwater harvesting performance
	5 kL tank and ARD system	For assessing the proposed adaptive rainwater diversion system

[¤] Based on the total roof area of 215 m^2 from the conceptual design of a residential estate with 15 allotments/ha (Water by Design 2010).

€ Refer to Table 2 for rainfall data statistics.
¥ Daily per capita consumption derived from summer 2009/2010 survey of Gold Coast dual reticulated dwellings (Willis et al. 2011). This is equivalent to a total annual consumption of 168 kL/dwelling, for the average sized dwelling of 2.5 occupants (ABS 3236.0 2010; Qld OESR 2010).
µ All non-potable fittings is 80% of total consumption (Willis et al. 2011).
§ Minimum fittings to be supplied with rainwater, in accordance with the mandate, are toilet cisterns, cold laundry taps and one external tap. This is 50% of total consumption (Willis et al. 2011).

Table 2 Rainfall statistics

Location	**Rainfall scenario**	**Average annual rainfall (mm)**	**Long term average annual rainfall (LTAAR) (mm)**	**Simulation period£**
Brisbane	below LTAAR	796	1090 (1890-2010)	7 years from 1/8/2000
Caloundra	equivalent to LTAAR	1482	1531 (1972-2010)	3 years from 1/2/2007
Gold Coast	above LTAAR	1631	1451 (1887-2010)	6 years from 1/10/1999

£ The pluviograph (6 minute rainfall observations) and mean monthly evapo-transpiration data provided with MUSIC was used for each simulation period. Where possible, periods of missing or accumulated data were avoided.

The reduced rainfall scenario is expected to be the most difficult to achieve dual performance and will be used for assessment in Brisbane. Clearly, under these conditions the water conservation performance will be compromised. Also, as the following compliance strategy discussion details, flow frequency management is achieved by capturing a daily target depth of runoff. This depth is fixed and independent of rainfall variation.

Dual performance is most sensitive to changes in catchment area, as this parameter directly scales inflow and runoff storage capacity. Thus, the performance investigations will commence with finding the optimum catchment area for the 5 kL storage.

Further to the consumption scenarios, consideration has been given to the variability of external water demand in response to environmental settings. A daily external demand index has been derived that accurately predicts (r^2=0.90) national monthly external water demand using climatic indices of rainfall and temperature. The model is validated by external demand surveys in Perth, Adelaide, Melbourne, Newcastle, Gold Coast, Toowoomba, Emerald and Mackay. Refer to Figure 1 for overall performance, further results will be separately published. Survey data used for validation discontinuously spans the period 1985 to 2010 (Qld DNR 2000; Loh & Coghlan 2003; Barton & Argue 2005; Willis et al. 2011). This daily index is combined with a diurnal pattern (Willis et al. 2011) to model consumption at hourly intervals.

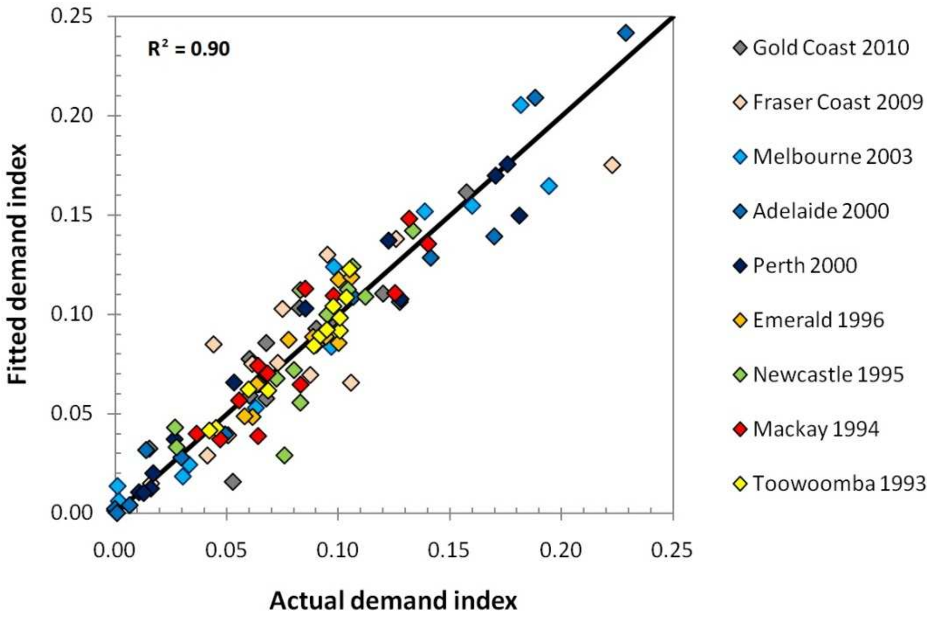

Figure 1 Overall performance of predicting national monthly demand variance from climatic indices of rainfall and temperature

Compliance strategy

For dual operation to be compliant the objectives of water conservation and runoff flow frequency management, as defined by WSUD guidelines (Water by Design 2009), must be simultaneously achieved.

The water conservation design objective reflects the Queensland Development Code Mandatory Parts 4.1, 4.2 and 4.3. Applicable to residential rainwater harvesting is Part 4.2 (Qld DIP 2007). For a new detached Class 1 dwelling a 5 kL tank shall achieve an annual mains water saving of 70 kL/dwelling in SEQ.

In this study, mains water savings are achieved in two ways: 1) Rainwater supply - where the rainwater harvest is used directly to reduce mains consumption of that dwelling; and 2) Rainwater diversion - where rainwater is diverted from the dwelling. This does not directly reduce mains consumption of the dwelling but, produces a water resource that is used by others to reduce mains consumption. In this way, total rainwater yield and mains water savings is the sum of rainwater supply and diversion.

The frequent-flow management design objective is achieved through capture and management of a daily runoff depth from all impervious surfaces of the catchment. The capture depth is dependent on the catchment impervious ratio, being the first 10 mm for a ratio equal to or less than 40% and the first 15 mm otherwise (Qld DIP 2009). The capture capacity needs to be renewed in 24 hours and management is through stormwater reuse, infiltration and/or evapo-transpiration. It is likely in most residential cases that reuse will be insufficient to solely renew capacity.

In this study, a fixed daily runoff capture depth is not targeted. Rather, the aim is for a variable depth that is statistically equivalent, by runoff frequency and average annual runoff volume, to a fixed depth of 15 mm/d. In this way, an equivalent management of stormwater flow frequency is achieved. Furthermore, targeting a varying depth that is equivalent to 15 mm/d can demonstrate compliance regardless of the imperviousness of the catchment.

Modelling software and processes

Rainwater performance at the allotment scale is derived through a water balance analysis, also known as behavioural simulation. A model was purpose built using Microsoft Excel as none of the current water balance applications were capable of modelling the new ARD concept.

Sources of loss included in the model are 1) evaporation from the roof 2) overflow from gutters during excessive rainfall; 3) losses from the leaf separator; 4) diversion by first flush; and 5) overflow from the tank. As the first flush of 20 L/d (AS HB230 2008) should be discharged in the same manner as the rainwater diversion and evaporation is a phase change, all other losses will contribute to runoff from the roof.

A maximum daily roof evaporation of 0.4 mm (Chapman & Salmon 1996) was adopted and is comparable to other rainwater performance studies (Lucas et al. 2006; Lucas & Coombes 2009). Overflow of gutters is regularly observed in Queensland. The aim of the Australian standard for roof drainage (AS 3500.3 2003) is to contain rainfall from a storm with an average recurrence interval of 20 years or less, when using eaves gutters. Clearly, this is not typically the case. This can be due to poor construction and lack of maintenance. Therefore, gutter and downpipe capacity will be based on what can be typically observed in SEQ, which is at least annual overflow. A 90 mm downpipe per 50 m^2 catchment and a Stramit Quad 115 gutter (Stramit 2010) will overflow on average once a year, in Brisbane (AS 3500.3 2003). This is equivalent to a maximum gutter flow of 1.4 L/s. There is a lack of published information on the efficiency of leaf separators .Therefore, efficiency is assumed to be 80% for flows greater than 1 L/s and 100% otherwise.

Furthermore, a 'spill before yield' simulation sequence ensures tank inflow immediately contributes to runoff if the water level is at the obvert of the overflow, regardless of the consumption that occurs during the time-step. Therefore, a conservative assessment of water conservation and frequent flow management is expected.

MUSIC was used to model runoff at the estate scale. The ARD system was simulated in MUSIC by importing reuse time series data into the rainwater tank nodes. This data was generated by the Excel model. Reuse was calculated at 6 minute intervals as the sum of supplied and diverted rainwater. In this way, MUSIC is able to simulate ARD, but not able to differentiate between rainwater supply and diversion.

MUSIC was also used to determine the average annual runoff volume and frequencies from an impervious catchment where an initial runoff capture depth is 15 mm/d. This can be simply simulated in MUSIC by applying a 15 mm/d rainfall threshold to an impervious catchment, which represents the connected roof area. The affect is, daily capture and management of runoff solely with evapo-transpiration and within 24 hours. The derived runoff volume and daily frequencies are used as thresholds that the ARD system cannot exceed.

Rainwater diversion release strategy

Under most circumstances diversion will be to the sewer, due to being readily available, so an appropriate release strategy is investigated. Following excessive rain events an inflow and infiltration spike can occur in sewer flows. Diversion must be avoided at this time to prevent overwhelming the system. Also, to the same effect, efforts should be made to avoid the normal diurnal peak flows. It is acknowledged that generalisation of the occurrence of sewer flow peaks should be avoided due to the complex hydraulics of a watershed which may include a mix of residential, industrial and commercial consumers, many of which with unique diurnal consumption patterns (Skowron & Chevalier 2008). However, for the purpose of this preliminary analysis, normal sewer flow is considered identical to the internal residential water use pattern.

To avoid diversion during a spike in inflow and infiltration, diversion will halt for 24 hours when high rainfall intensity or high daily rainfall is detected and will resume when the 24 hour rainfall is below a lower threshold. An event frequency of at least five time per year was assumed In this study. To avoid diversion during the normal peak flow, which can be seen later in an example storm event (Figure 5), diversion will start at 21:00 and last for a period of 9 hours. As the system detects reduced consumption, and needs to divert more rainwater, the duration will be extended by starting earlier. In this way, the morning peak will be avoided for all but the lowest consumption scenarios.

Release could also discharge to schemes such as stormwater harvesting, greywater harvesting or other forms of dual reticulation. In these cases, an independent release strategy would be required. However, it is believed that each of these alternatives would be constrained only by peak inflow or peak normal flow. Therefore, a release strategy could be formed by relaxing conditions of the sewerage strategy.

RESULTS AND DISCUSSION

As previously stated, dual performance is most sensitive to changes in catchment area. Figure 2 shows performance in response to catchment change.

With a catchment of 100 m^2 the water savings capacity of a conventional 5 kL tank is less than the 70 kL target. Under this arrangement inflow is too low and irregular. However, the runoff volume is easily below the threshold. Further investigation showed, with rainwater diversion the mains water savings still failed to reach the target. Thus, when following the catchment area of the mandate the system is operating inefficiently and cannot achieve the water conservation objective. Therefore, this connected roof area is precluded from further investigation.

With a catchment of 150 m^2 the conventional tank achieves the water saving target and water conservation objective. Furthermore, the runoff volume marginally exceeds the threshold. In this case, minimal rainwater diversion would be needed to reduce runoff to an acceptable volume. Clearly, this is the optimum connected roof area for a dual purpose 5 kL rainwater tank in Brisbane.

With a catchment of 200 m^2 the conventional tank can exceed the water saving target; however the amount of diversion needed to achieve an acceptable runoff volume may breach the diversion strategy. Clearly, this needs to be avoided to prevent overwhelming the capacity of the receiving system. It should be noted with larger storage, this scenario can become the optimum. For this reason, investigation of catchment areas greater than 150 m^2, as typically offered with cluster tanks and group housing, will be precluded from this preliminary analysis. This is the subject of ongoing research.

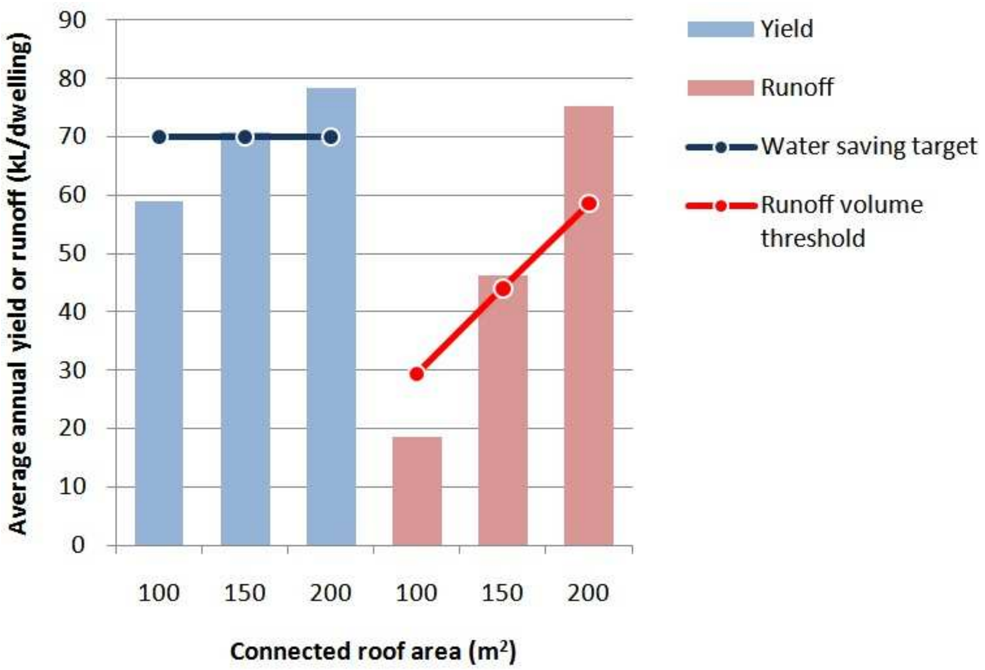

Figure 2 **Average annual yield and runoff from conventional rainwater harvesting, when supplying all non-potable fittings, for the average sized dwelling in Brisbane and with performance by connected roof area**

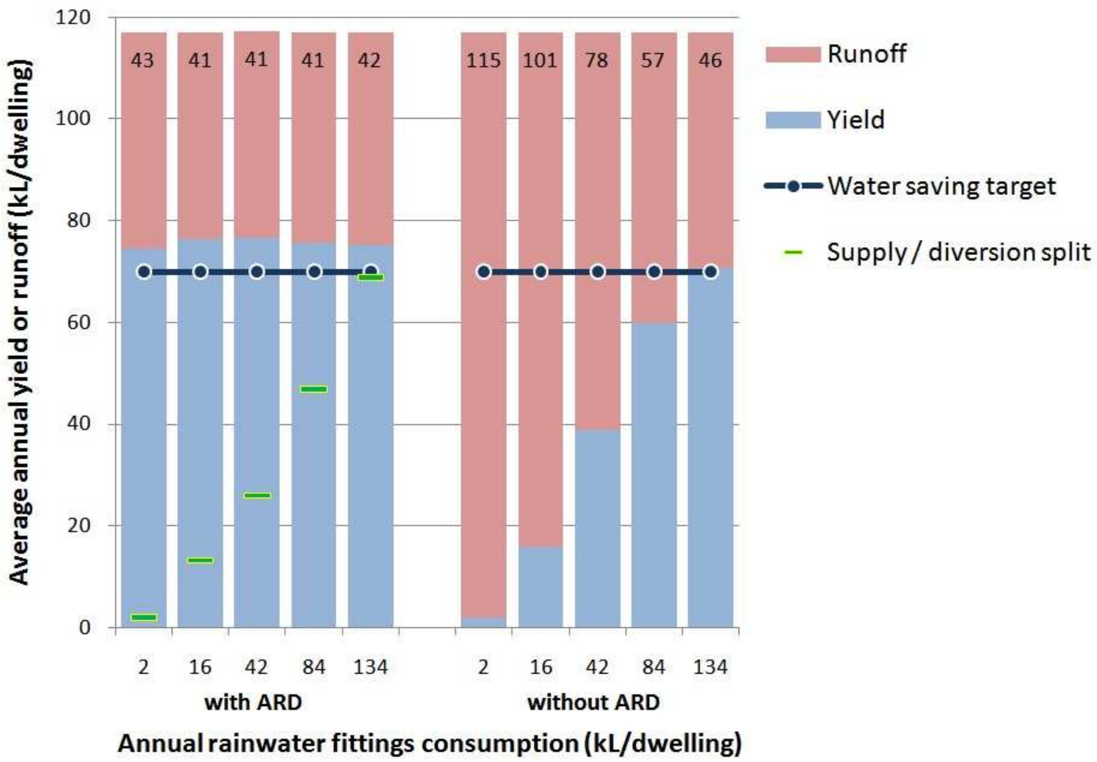

Figure 3 **Rainwater harvesting dual performance with and without ARD, for a connected roof area of 150 m^2, in Brisbane and with performance by consumption scenario**

Figure 3 illustrates the average annual yield and runoff from all scenarios studied in Brisbane and for a conventional 5 kL rainwater tank with and without ARD. Without ARD the system fails to achieve the mains water saving target of 70 kL/dwelling/yr for all but the highest consumption scenario, which itself is above the mandate specifications. Thus, attaining the water conservation objective solely with conventional rainwater harvesting is unlikely in Brisbane under below-average rainfalls.

From all ARD scenarios, the mains water saving target is achieved. The saving is the sum of rainwater supplied and diverted and the split between the two is shown (the volume below the split marker is rainwater supply). It should also be noted that diverted water is only from the roof catchment and no other urban surfaces. Therefore, the system is compliant with the water conservation objective in Brisbane regardless of the dwelling consumption or the fittings supplied with rainwater. Furthermore, this demonstrates how a vacant or partially occupied dwelling can contribute to securing urban water resources by producing an alternate water supply for others through rainwater diversion.

The minimal effect from introducing the ARD system on rainwater supply can be seen by comparing the ARD supply / diversion split marker with the yield from the system without ARD. For low and high consumption there is little difference. It is believed with refinements to the diversion release strategy, a greater convergence can be achieved for intermediate consumption.

Figure 3 also demonstrates under the ARD system the annual runoff volume is not greater than 43 kL. The runoff threshold from a 150 m^2 impervious catchment in Brisbane was estimated at 44 kL, refer to Figure 2. Thus, the ARD system achieves an equivalent daily capture depth of 15 mm or more by measure of annual runoff volume and is in part compliant stormwater flow frequency management objective. Not shown on Figure 3 is the split between the causes of runoff. For the period of simulation they are, gutter overflow (5.1%), losses due to leaf separators (4.6%) and tank overflow (90.3%).

For the system without ARD, it can be seen in all scenarios that runoff volume exceeds the 44 kL/yr threshold. With the rainwater consumption scenarios of 42 kL/dwelling/yr or less, the exceedance is very high. This demonstrates how with diminishing consumption and rainwater yield variability, the stormwater management results from conventional rainwater tanks cannot be assured.

Finally, Figure 3 demonstrates, when fitting the ARD system, the time to completely drain the tank from full and without inflow (critical period) remains constant regardless of diminishing consumption. This can be seen by the uniform ARD rainwater yield.

Figure 4 shows runoff flow frequencies for runoff events of 10 kL/day or less from a 150 m^2 catchment of alternate conditions. The impervious result represent a vacant dwelling or dwelling without rainwater consumption. The forested result represent the catchment prior to urban development. It can be seen that the runoff frequency for the ARD system does not exceed the frequencies from the developed surface with a 15 mm/d runoff capture. This now demonstrates full compliance with the stormwater flow frequency management objective.

It should be noted that this solution does not converge with the pre-urbanised hydrology for the runoff values shown. The runoff frequency of a conventional rainwater tank shown are for the 84 kL/dwelling/yr rainwater consumption scenario, which is in accordance with the mandate.

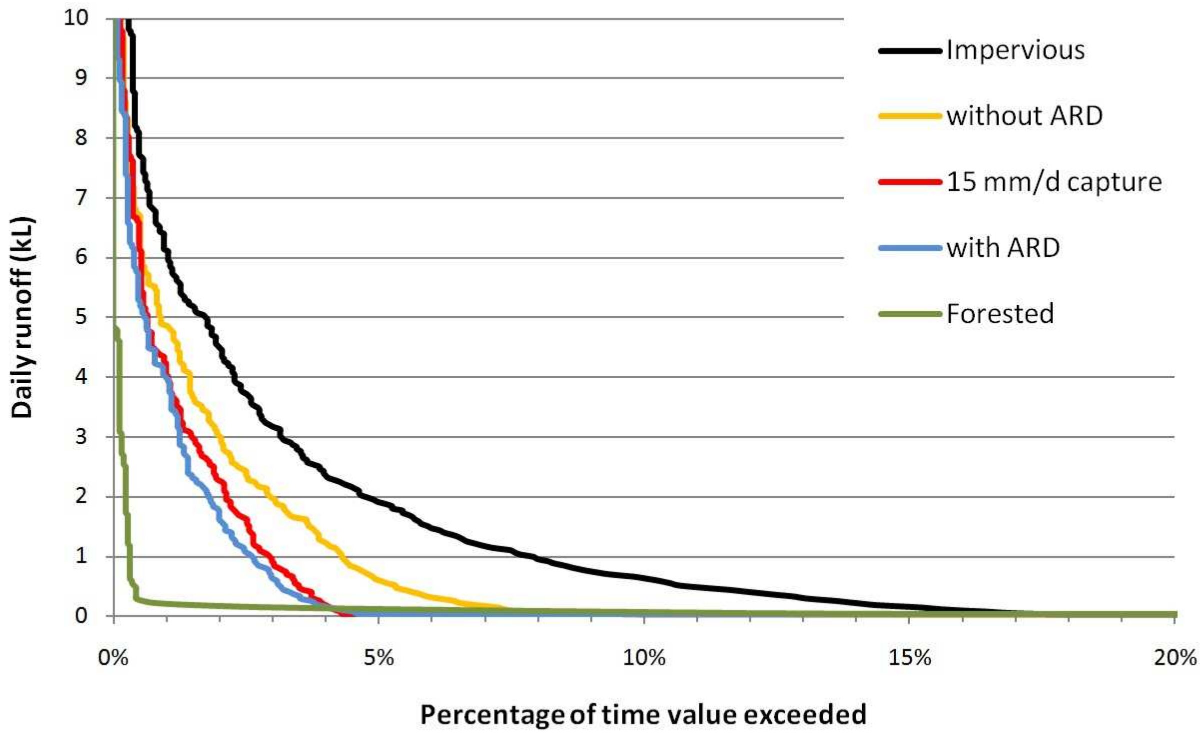

Figure 4 Flow duration curve for runoff events from 150 m^2 catchment under different conditions in Brisbane

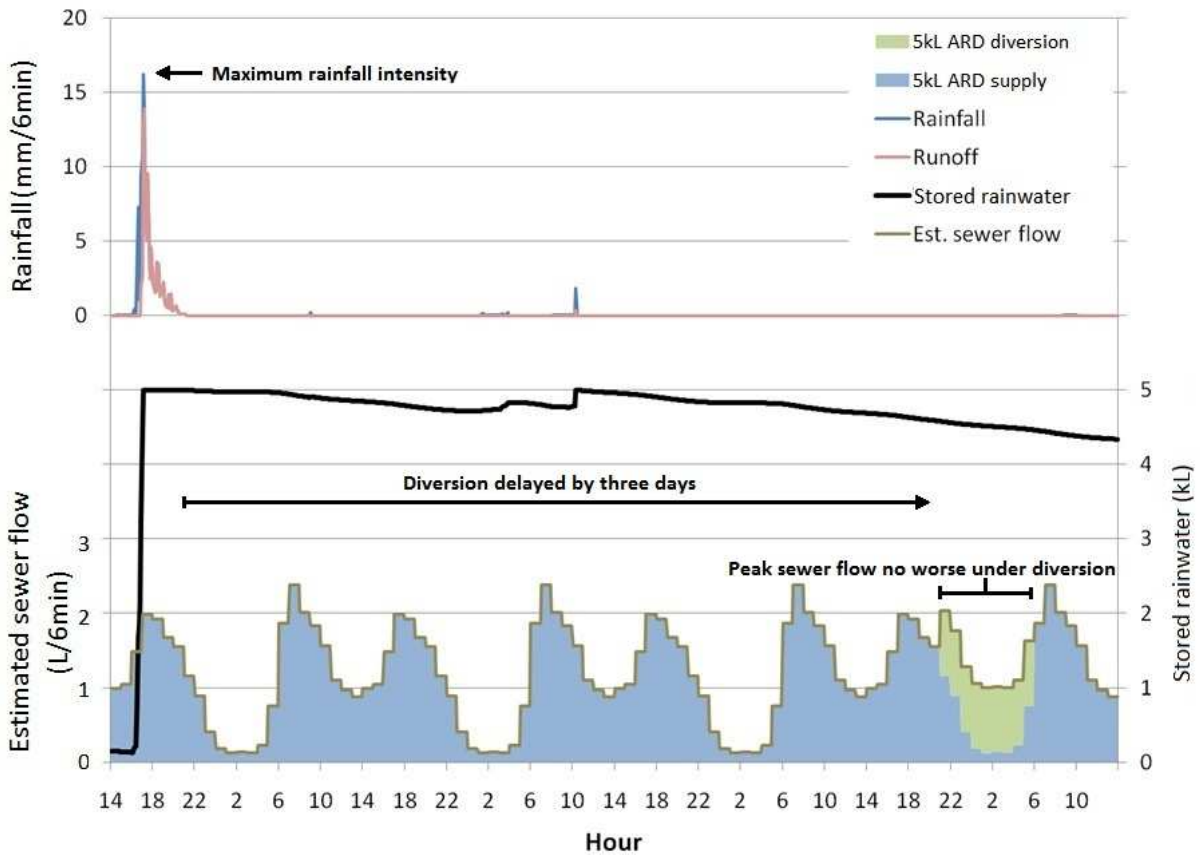

Figure 5 ARD system response to an excessive rainfall event for Brisbane

Figure 5 shows output from the behavioural simulation of the ARD system. The consumption scenario is supplying all non-potable fixtures for the average size dwelling in Brisbane and diversion is to the sewer. The rainfall event shown was a seven hour storm that occurred on the 9/3/2001 with a total rainfall of 138 mm and 6-minute maximum intensity of 162 mm/hr.

The timing of this event is significant, as March is on average the third wettest month in Brisbane and marks the end of the notable wet season. This can be seen by inspecting online monthly rainfall data (BoM 2011). Normally after three month of reasonable rainfall conventional rainwater tank would be reasonably full. However, the tank is virtually empty due to the ARD system. This allows for a daily capture depth of the first 32 mm of runoff from this event.

After this event, the largest in the seven years of simulation, and events of smaller recurrence intervals, significant inflow and infiltration of runoff would enter the sewer. For simplicity, this is not shown in the estimation of sewer flows. In accordance with the release strategy, diversion is halted for at least 24 hours and until the 24 hour rainfall is below a minimum threshold. This delays diversion to more than three days after the rain event concludes. Normal diversion then resumes at 21:00. During this time the peak sewer discharge is less than the normal daily peak and the midnight flow increases to approximately midday levels. This demonstrates the release strategy avoids diversion during high sewer flows from excessive rainfall and normal flow fluctuation.

Figures6 and 7 illustrates performance at the Gold Coast and Caloundra for periods where rainfall is above and equivalent to the long term average, respectively. In these locations, the thresholds of annual runoff to meet the flow frequency requirements are 128 kL/yr and 90 kL/yr, respectively. In these analyses, the release strategy for Brisbane was adopted with minor changes to parameters. With minor exceptions, both water conservation and stormwater management objectives have been simultaneously achieved with the ARD system.

Some notable differences to the Brisbane study are 1) the differential between rainwater supplied to the dwelling for the systems with and without ARD has increased; 2) in all cases the diversion is notably higher, which may challenge the release strategy; and 3) the mains water savings offered with the ARD system are in the order of 50% to 100% more than the target. This demonstrates a fixed water saving target for SEQ fails to capture the full potential of rainwater as alternate water source. The regulation should identify and exploit areas that are capable of exceeding performance. Overall, the plausibility of broader application of the ARD system throughout SEQ and in periods of average and above average rainfall is demonstrated.

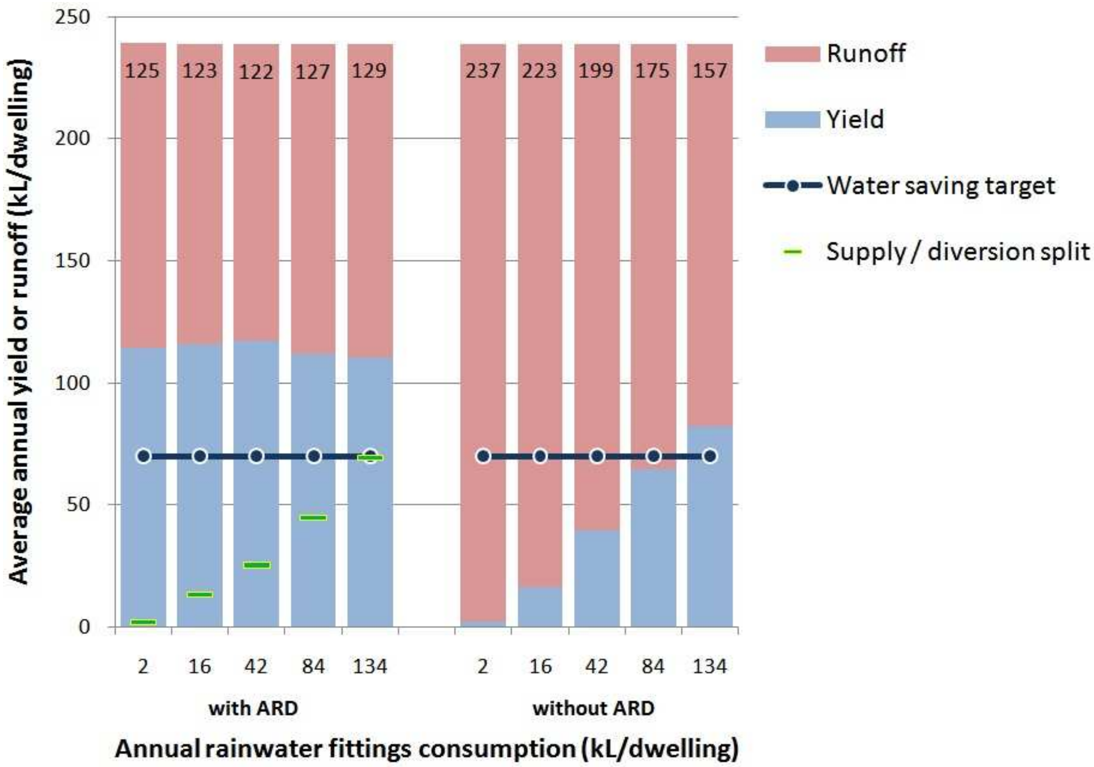

Figure 6 **Rainwater harvesting dual performance with and without ARD, for a connected roof area of 150 m^2, in Gold Coast and with performance by consumption scenario**

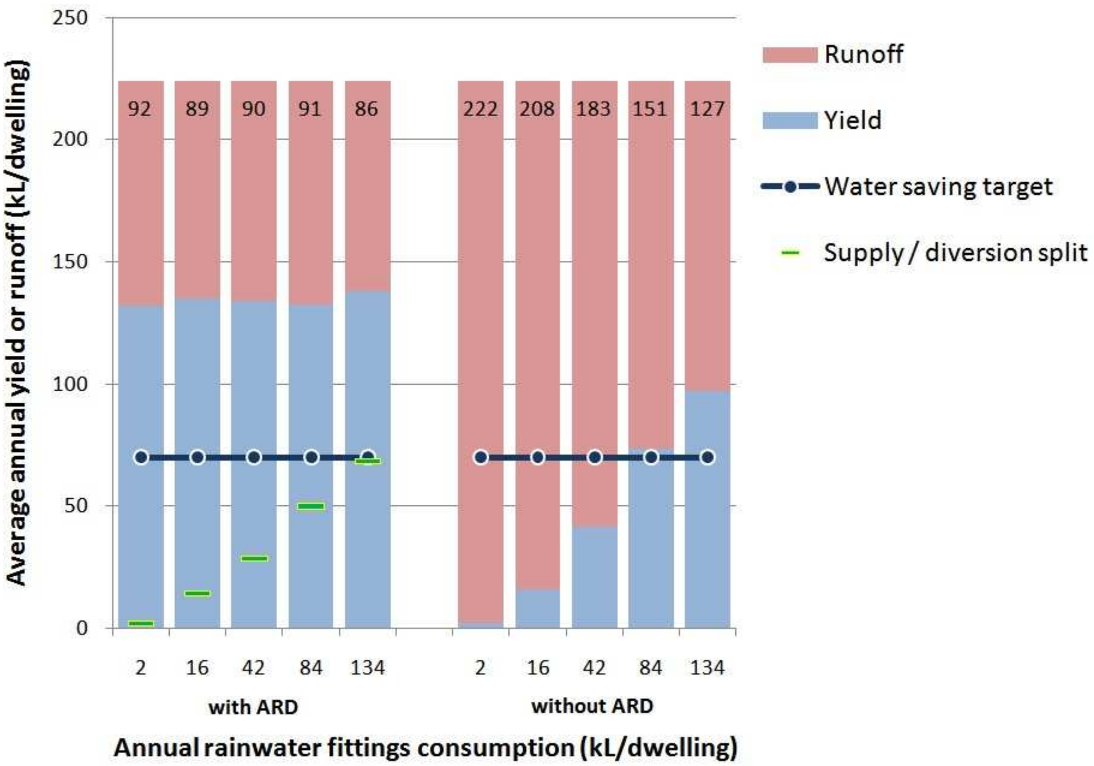

Figure 7 **Rainwater harvesting dual performance with and without ARD, for a connected roof area of 150 m^2, in Caloundra and with performance by consumption scenario**

CONCLUSION

Behavioural simulation of a hypothetical setting for a single residential rainwater harvesting system has shown a conventional 5 kL rainwater tank is:

- Unable to achieve the water conservation objective under below-average rainfall, when following the mandate for detached dwellings in Brisbane. The average annual mains water saving is less than the target of 70 kL/dwelling.
- Able to achieve the water conservation objective, with conditions of, a connected roof area of 150 m^2 or greater, supplying rainwater to all non-potable fittings and with consumption equal to or higher than the current dual reticulated consumption of the average sized dwelling. Under these conditions, the roof area and the fittings supplied with rainwater are above the mandate minimum.
- Unable to achieve the frequent-flow stormwater management objective. Runoff volumes and frequencies exceed thresholds, which were derived from MUSIC modelling of an impervious catchment of 150 m^2 with daily capture and management of the first 15 mm of runoff.

The simulation also shows a 5 kL rainwater tank fitted with adaptive trickle diversion is:

- With some minor exceptions, able to achieve the mains water saving target and water conservation objective regardless of the dwelling consumption, the fittings supplied with rainwater, the selected locations in SEQ, and the rainfall being below, equivalent to or above long term average; but, with the condition of a minimum connected roof area of 150 m^2;
- With some minor exceptions, able to simultaneously achieve the frequent-flow management objective regardless of the imperviousness of the catchment, the dwelling consumption, the fittings supplied with rainwater, the selected locations in SEQ and the rainfall being below, equivalent to or above long term average; but, with the condition of a maximum connected roof area of 150 m^2;
- Able to achieve a supply of rainwater for the dwelling that is similar to a conventional rainwater system;
- Able to adapt independently to changes in consumption and rainfall by adjusting the volume of daily rainwater diversion; and
- Able to divert rainwater into the sewer system without potentially increasing typical daily peak flow rates, and by this way, creating a secondary function for the sewerage system of rainwater diversion reticulation.

With rainwater diversion to the sewer, ARD brings financial incentives for government and municipal authorities. Due to a reduction in allotment runoff volume, the scale of WSUD element can be reduced. A similar reduction in construction and maintenance costs of these elements is expected. Furthermore, a reduction in stormwater treatment area could potentially increase allotment yields and Council rates. Finally, utilities gain control of and revenue from a new water source from residential rainwater diversion.

Finally, a water sensitive city must have adaptive and multifunctional infrastructure and urban design, among many other capacities. Responsive rainwater diversion is adaptive to variation in rainfall and household consumption and brings a secondary function to sewerage reticulation. Thus, with ARD, we can approach water sensitive cities, which is the ultimate goal of water sensitive urban design.

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