Rethinking of Non-traditional Water Resources in Residential Developments of Rural Towns, Western Australia

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ABSTRACT

Rainwater collected from residential roofs and greywater generated from domestic uses except toilets are viewed as possible substitutes for high grade water sources which supply non-potable indoor uses and irrigation in Australia. This paper searches for alternatives by adopting roofwater and greywater in residential envelope as per Australian water standards. This study provides the results of greywater recycling, which contributes to the greater saving of mains water supply than rainwater use, and which reduces more than half of the wastewater to receiving waters in the rural township of Cranbrook, Western Australia. Similarly, capturing rainwater can mitigate approximately 48% stormwater drainage in this study area. This research endeavours to offer a typical paradigm for an integrated water system in the rural residential sectors.

Keywords: greywater recycling, rainwater harvesting, residential developments, rural towns, imported water saving

INTRODUCTION

In terms of residential water consumption, the volumes can be ordered as 380 L/p/d (US), 340L/p/d (Canada), 265L/p/d (Spain), 181L/p/d (Australia), 85L/p/d (Lithuania) (EEA, 2003; Loh and Coghlan, 2003; Racoviceanu, 2005). Augmentation of water supply in both urban and rural area is continuing. It is a great challenge to ensure the supply of high-quality and sufficient water for all domestic water use because of climate change, surface and ground water pollution, rapidly growing water consumption, as well as financial cost. For all residential water use, only a small portion serves potable quality purposes. The remaining non-potable uses, such as toilet flushing and garden irrigating, can satisfactorily be supplied with alternative water sources. In this way reducing the costs associated with water supply, stormwater and wastewater discharge, ultimately lead to a more sustainable use of natural water resource and the protection of the ecological balance in aquatic ecosystems. Capturing rainwater and reusing greywater (greywater can broadly be defined as all wastewater generated in the household, excluding toilet waste) are increasing practices in the area of water research in the last decade, particularly in countries where regulations encourage these practices and by-laws, such as US, Australia and Germany (Racoviceanu, 2005).

Previous studies on rainwater and greywater chiefly focus on urban area (Christova-Boal and McFarlane, 1996; Herrmann and Hasse, 1997; Dixon, 2000;

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Eriksson and Henze, 2002; Brown, 2003; Friedler, 2006; Grant and Pamminger, 2006; Coombes, 2007; Ghisi, 2007; Madungwe and Sakuringwa, 2007). In contrast, this paper seeks for explored water sources supplying toilet flushing and landscape watering in the rural town of Cranbrook, Western Australia. It endeavors to achieve a paradigm shift especially for newly built rural residential developments, with promoting rainwater adopting and greywater recycling as parts of integrated water management.

METHODOLOGY

Description of Study Area and Climate Data

The township of Cranbrook is located in the Great Southern Region, Western Australia, at coordinates of 34°18'S and 117°33'E. Fig. 1 provides the location of the study catchment and residential land use details.

Fig. 1 - Location and residential land use of Cranbrook

The historical daily climate data over 57 years (from 1950 to 2006) is used for modeling purposes in this case. The average annual rainfall for this climate series is 490 mm ranging from 310 mm to 682 mm and the average annual pan evaporation is 1439 mm from 1267 mm to 1577 mm. the long-term average annual number of rain days for Cranbrook is 131. The modeling of this study is based on the average roof area of 249 m² and 2.4 persons per block (Western Australian Department of Planning and Infrastructure and Australian Bureau of Statistics, 2007). Table 1 indicates the relevant properties associated with modeling and analysis in this case study.

Table 1 Properties of Cranbrook

Properties	Values
Rainfall(mm) ^a	490
Evaporation(mm) ^a	1439
Population ^b	270
Study Area (ha) ^c	29.6
Water Consumption(ML/yr) ^d	30.6

Notes:

a Climate data was adopted from SILO Data Drill (<http://www.nrw.qld.gov.au/silo/datadri1>, data edited as per reference (Jeffrey and Beswick, 2001));

- b Population data was sourced from the Australian Bureau of Statistics, 2007;
 c Topographical data was supplied by Western Australian Department of Planning and Infrastructure; and
 d End use data was stemmed from Water Corporation of Western Australia.

Alternative Options

Seven proposed alternatives were selected to achieve the expected water reduction during the study period. A summary of the scenarios being modeled is shown in Table 2.

Table 2 Water servicing options to be modelled

Options		Description of Options
Base case	A	Traditional Water System
Rain water use	B	Adopting Rainwater for Garden Irrigation
	C	Adopting Rainwater for Toilet Flushing
	D	Adopting Rainwater for Toilet Flushing and Garden Irrigation
Grey water reuse	E	Reuse Treated Greywater for Garden Irrigation
	F	Reuse Treated Greywater for Toilet flushing and Garden Irrigation
	G	Reuse Treated Greywater for Toilet Flushing
	H*	Direct untreated greywater subsurface irrigation

Note: *water from shower, hand sinks and laundry rinse.

Water Balance Method

A water modeling software 'AQUACYCLE' (Mitchell and McMahon, 2001) is adopted to compute water balance results for each of various water servicing options considered in this paper. This computer model which runs on daily time step views water supply, stormwater flows and waste water network as a more holistic framework in terms of integrated water management. Calibration parameters are determined by comparing the actual water consumption derived from Water Corporation of Western Australia to modeled data. A running calibration parameter set fitted to the water balance modeling is listed in Table 3.

Table 3 Aquacycle input parameters

Parameters	Values
Capacity of soil store 1 (mm)	50
Capacity of soil store 2 (mm)	120
Roof area maximum initial loss (mm)	1
Paved area maximum initial loss (mm)	1.5
Road area maximum initial loss (mm)	1.5
Base flow index (ratio)	0.1
Garden trigger to irrigate (ratio)	0.22

RESULTS

The modeled results of the residential development of Cranbrook are shown as Fig. 2 and Fig. 3 for rainwater harvesting options; Fig. 4 and Fig. 5 for greywater recycling system.

Rainwater Use System

(1) Dimension of Rainwater Tank

Volumetric reliability herein is defined as the percentage of total demand met over the logging period, which is presented in Eq. (1).

$$VR(\%) = \frac{\sum V_R}{\sum V_T} \times 100 \quad (1)$$

Where V_R is the yearly volume of replaced potable water (ML/yr) and V_T is annual water demand (ML/yr).

When only rainwater is considered, the curves in Fig. 2 illustrate reaching the maximum volumetric reliability for option B (80%), C (100%) and D (62%) with tank sizes 147 m³, 12 m³ and 75 m³, respectively. It can also be observed that option C is much more likely to meet the most amount of water demand. As a compromise among volumetric efficiency, final cost and available space, tank sizes for these described three options have been adopted as 30 m³, 12 m³ and 30 m³ respectively.

Fig. 2 - Volumetric reliability of rainwater storage for varying tank size

(2) Water Balance Results

In the scope of this study, imported water, stormwater and wastewater are considered as an integrated water system instead of separate ones.

Option A is the traditional water system (base case) with imported water, stormwater and wastewater decentralized (end-of-pipe solution). On the contrary, option B, C and D are sustainable alternatives which are promoted as a comprehensive framework to analyze total scheme water saving and discharges to receiving waters (Fig. 3).

Fig. 3 - Water balance of option A, B, C and D

Notes: IW refers to Imported Water; SW is Stormwater; WW is Wastewater; and RWTU means Rainwater Tank Use

It can be noted that the annual imported water quantities for option A, B, C and D are 297.6 m^3 , 238.9 m^3 , 261.1 m^3 and 222.8 m^3 , and wastewater discharge is around 161 m^3 . It has been seen that yearly stormwater runoff predicts in Fig. 3 are 85.8 m^3 , 105.3 m^3 and 71.3 m^3 , and storage rainwater use is 68.1 m^3 , 32.7 m^3 and 68.3 m^3 for option B, C and D, respectively.

Greywater Recycling System

The supplied water consumption data for Cranbrook recommend the quantity of toilet flushing covering 21% of all domestic water use. Using greywater for toilet flushing only would be marginally necessary because of large volumes of overflow. In order to take full advantage of greywater, the authors deem a combination of toilet flushing and garden irrigating in the household scene as more viable. Therefore, in this paper, option G is not considered in detail.

Untreated greywater flowing directly to subsurface irrigation as a simple and safe means is acceptable by Australian water authorities and residents. This will decrease human exposure to the used water. Immediate reuse (storage time not more than 24 hours) is a key factor for greywater avoiding anaerobic state.

The following is a discussion of greywater recycling in residential subdivision Cranbrook.

(1) Dimension of Greywater Tank

Fig. 4 gives clear volumetric reliability changing trend with adoption of greywater for garden irrigation and toilet flushing and garden irrigation.

Fig. 4 - Volumetric reliability of greywater storage for varying tank size

It states that in order to achieve the most adequate efficiency for options E and F, the necessary tank volumes should be 75 m^3 and 55 m^3 . Assuming it to be an appropriate balance among greywater tank storage, reliability and costing, tank size 3 m^3 is chosen for these two options. The same tank volumes are adopted for option H.

(2) Water Balance Results

Water from the kitchen, bathroom and laundry can be reused for garden watering and toilet flushing. It is necessary to need greywater treatment plant in options E and F.

Fig. 5 – Water balance of greywater use system

Notes: GWTU is Greywater Tank Use and GWTP means Greywater Treatment Plant

The estimated annual imported water quantities are 221.2 m^3 , 201.0 m^3 and 238.1 m^3 for these three scenarios, with stormwater discharge around 137 m^3 . It can also be formulated to show yearly wastewater discharge of 92.9 m^3 , 74.8 m^3 and 108.8 m^3 , with treated greywater reuse quantities 69.9 m^3 and 88.1 m^3 for options E and F respectively, 54.0 m^3 untreated greywater directly reused for option H.

Reduction in Imported Water, Wastewater Discharge and Stormwater Runoff

Reduction evaluates the alternatives performance of this residential sector. Using the appropriate tank sizes and statistical analysis method, results of average annual percentage reduction in scheme water supply, wastewater and stormwater discharge for all proposed scenarios comparison to base case are given in Table 4.

It has been seen that the percentage saving on imported water supply for rainwater

usage options spans from 12.3% to 25.1% comparison with greywater reuse 20.0% to 32.5%. Similarly, reduction on wastewater discharge ranges from 33.2% to 54.1% for adopting greywater, and stormwater runoff reduction percentage is from 23.4% to 48.1% for rainwater scenarios.

Table 4 Reduction of imported water supply, wastewater and stormwater discharge

Options		Reduction		
		Imported Water (%)	Wastewater Discharge (%)	Stormwater Runoff (%)
Rainwater use	B	19.7	1.2	37.6
	C	12.3	0.6	23.4
	D	25.1	1.3	48.1
Greywater reuse	E	25.7	43.0	0.2
	F	32.5	54.1	0.2
	H	20.0	33.2	0.2

DISCUSSION

Water Quality

Scientific evidence has confirmed that water obtained from residential roofs is acceptable for most household uses. A study undertaken in Queensland, Australia (Coombes, 2003) reported that the quality of rainwater collected from roofs was suitable for toilet flushing and hot water uses. Also it is stated (Herrmann and Schmida, 1999) that the use of rainwater for clothes washing is safe. In this case study, using a fine-mesh intank filtration over all inlets and outlets and sedimentation in the tank to remove debris and minimize the need for maintenance. Rainwater harvesting for toilet flushing and garden watering in residential scope is considered a feasible water source or conservation measure in Cranbrook.

Greywater contains fewer pathogens and 90% less nitrogen than toilet water. Therefore, the greywater treatment process is less complex and cheaper than sewer wastewater. Research reports that the common greywater treatment mechanisms are constructed wetlands, modified sand filters, wet composting, amended soil filter, basic two-stage systems (coarse filtration plus disinfection), biological systems (membrane bioreactors (MBR), biologically aerated filters (BAF) and rotating biological contactor (RBC) (Al-Jayyousi, 2003; Madungwe, 2007). In comparison to traditional treatment methods, these technologies are simpler and cheaper. The quality of effluent from greywater treatment plants (Nolde, 1999; Al-Jayyousi, 2003; Winward, 2007) shows that technologies documented above are competent for coping with Australian domestic recycling water standards. In this project, the recommended on-site greywater treatment technology is MBR followed by ultraviolet disinfection. Treated greywater is believed to be reliable and consistent for garden irrigation and toilet flushing and irrigation in Cranbrook.

Tank Capacity

The curves (Fig. 2 and Fig. 4) reveal percentage reflection of the available water

consumption and the water needed in per residential lot. Rainwater tank and greywater tank capacities ideally are taken at the points where the curves begin to flatten with consideration of volumetric efficiency, costing and space. The explanation of these different reliability trends is that the extreme variation in rainfall patterns and irrigation consumption for scenarios B, D, E and F comparison of option C. The curves demonstrate that greywater reuse holds the significant potential to cater for selected water use. A possible reason is the steady and higher water provision. It should be noted that the high garden irrigation demand mitigates the difference between the effectiveness of options B and D, as well as options E and F.

Water Balance

Figures and tables surrounding water balance and annual reduction for alternatives imply that greywater reuse outperforms rainwater use in saving imported water with smaller tank volumes. This is the reflection of higher usage for storage water in these two options. It is apparent that greywater recycling is more beneficial to decrease wastewater discharge to water bodies. It is also obviously seen that rainwater has greater impact on reducing stormwater runoff than greywater reuse which would mitigate drainage system stress.

Further Alternatives for Rainwater and Greywater Use

The most common use of rainwater and treated greywater is for indoor and outdoor non-potable purposes, the second major application being crop irrigating, others include tree nurseries, fire sprinklers, cleaning, car washing and livestock watering etc.. Further alternatives should focus on reducing urban salinity which is the problem which Cranbrook and other sites in Western Australia are suffering.

Existing Issues

It may be necessary to have dual water systems to use both roofwater/greywater and scheme water when the tank level is low due to dry weather or high usage. This ensures a reliable water supply that will still provide significant scheme water savings and stormwater management benefits, but increasing final costing at the same time.

Using fluctuant rainfall would be confronted with the condition that the marginally effectiveness in much rainfall days and limitation use in insufficiency precipitation period. Reuse of treated greywater in residential envelope is still to be a great challenge of community confidence in reliability and trustworthiness of this recycling system. The economic feasibility is indeed the barrier for recycled greywater uptake.

CONCLUSIONS

Harvesting rainwater and reclaimed greywater holds the potential for fresh water conserving, wastewater and stormwater discharge reducing, and should also be considered in terms of its contribution to integrated water management system.

Seven possible options adopting roofwater and greywater separately were estimated for rural residential development in the township of Cranbrook.

The results of this study provide greywater usage (maximum reduction 32.5%) more significantly reduces scheme water supply than rainwater harvesting (maximum

reduction 25.1%). Use of greywater on individual residential lots has the dramatic effect for drainage system by reduction approximately 54.1% or 88.1 m³/lot/y. The results of rainwater use analysis show explicitly that rainwater tanks are much more effective in intercepting roof runoff, with the maximum stormwater reduction 48.1% or 68.3 m³/lot/y.

To achieve water resources conservation, other measures such as water efficient domestic appliances, revised garden landscaping, leakage control, pricing policies and social water reduction education would also contribute greatly.

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