TOWARDS SUSTAINABLE WATER STRATEGIES IN THE PERTH REGION OF WESTERN AUSTRALIA: INCLUSION OF DECENTRALISED OPTIONS

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Abstract

This study presents the impact of including decentralised rainwater harvesting, water efficient appliances and wastewater reuse strategies in analysis of the operation of regional water supply systems. These strategies provide significant reduction in regional water demand, improvement in regional water security, decreases in greenhouse gas emissions and economic benefits. A compelling case has been made for the inclusion of decentralised water management options in analysis of regional water systems. This is a contrast to the normal practice of uncritical dismissal of decentralised options prior to detailed systems analysis. The results indicate that adoption of 3 kL rainwater tanks for hot water and laundry uses, water efficient appliances and estate scale wastewater reuse for outdoor and toilet uses for all new housing, and 3 kL tanks for laundry, toilet and outdoor uses with water efficient appliances at a rate of 1% per annum to existing houses may be optimum.

Introduction

About 1.5 million people currently occupy the Perth region in the south western corner of Western Australia that extends from Quinns Rocks in the north to Mandurah in the south. The Water Corporation is responsible for providing water and sewerage services to the region via an integrated water supply system that also supplies the Goldfields and agricultural areas (Water Corporation, 2002). The region is experiencing a population growth of 1.7% per annum and currently has an annual water demand of about 270 GL. The water supply system provides water from regional surface storages with a total volume of about 830 GL and combined surface areas of 11,200 Ha that collect rainfall runoff from catchments with a combined area of approximately 3,580 km^2. About 60% of the region's water demand is also supplied from ground water extracted from extensive aquifers in the Perth region. In response to expected water shortages in the future a desalination plant has been constructed at Kwinana that will supply water at 45 GL/annum to the Perth region. During the last 30 years the Perth region has experienced a 10% decline in average annual rainfall that has translated into a 50% reduction in rainfall runoff to dams (ASTE, 2002) as shown in Figure 1.

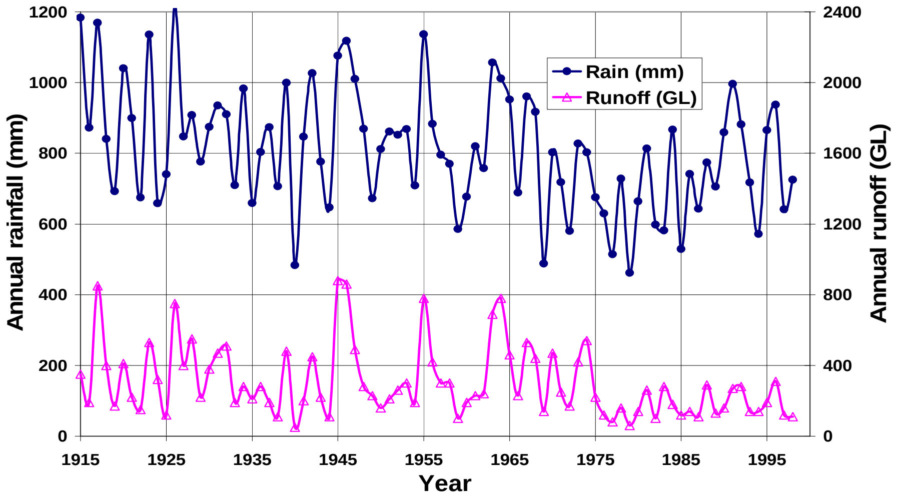

Figure 1: Annual rainfall at Midlands and runoff into regional surface storages

Figure 1 shows that rainfall at Midlands and runoff in the regional water supply catchments declined during the late 1970s. Since that period the average volume of runoff into regional water storages has been relatively constant at 167 GL/annum whilst the average volume of runoff during previous period was about 338 GL/annum. Interestingly the depth of annual rainfall at the urban fringe area of Midlands is seen to increase since 1975 and clear multi-decadal patterns are observed across the entire rainfall record. The low rainfall period that commenced in the late 1970s may be a consequence of normal climatic cycles that are also influenced by climate change induced by an emerging greenhouse effect. Regional climate models developed by CSIRO to understand the greenhouse effect estimate that changes in annual rainfall by 2030 in the south west of Western Australia will range from an increase of 5% to a decrease of 20% whilst by 2070 this range may be an increase of 20% to a decrease of 60%. However, AST (2002) suggest that climate change models produce reasonably robust global estimates but are not reliable for regional predictions.

Water supply strategies for the Perth region are dominated by a focus on regional solutions including surface storages, extraction of groundwater from aquifers, construction of desalination plants and pipelines from other regions. There is little or no critical analysis of decentralised water supply or management options in regional water strategies for Perth. Notably the report by the Australian Academy of Technical Sciences and Engineering (AST, 2002) on Perth's Water Balance – the way forward does not mention domestic rainwater harvesting and The Water Corporation (2002) uncritically dismisses the use of rainwater tanks to supplement mains water supplies in the region with the claim that "tanks rely on rainfall and can only produce a small percentage of average annual domestic water requirements". This statement seems at odds with the rainfall pattern shown for Midlands (Figure 1) and the average annual rainfall for Perth shown in Figure 2.

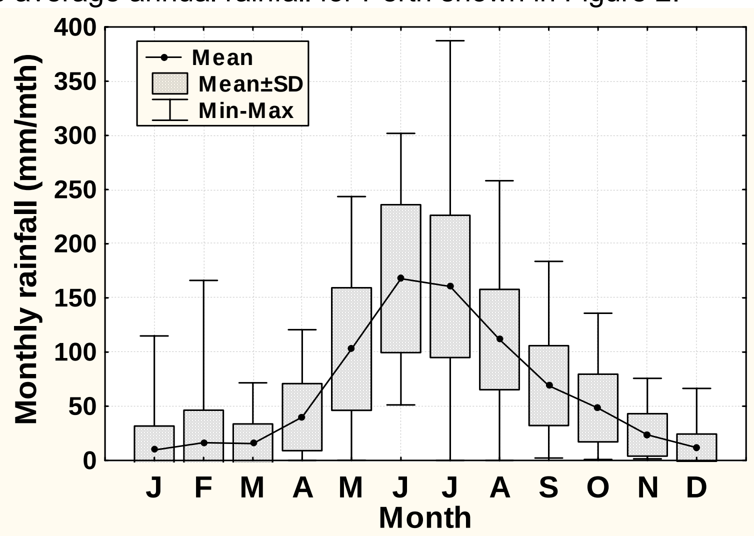

Figure 2: Monthly rainfall distribution at Perth Airport.

Figure 2 shows that Perth experiences seasonal rainfall that is dominated by rainfall during the April to October period whilst the period November to March that corresponds with likely higher outdoor water demands receives lower monthly rainfall. Nevertheless, Perth appears to experience sufficient annual rainfall for domestic rainwater harvesting to provide significant reductions in mains water demands. Indeed Coombes and Barry (2006) found that annual mains water savings from use of rainwater tanks to supply hot water, laundry, toilet and outdoor uses in Perth ranged from 54.3 ± 7.1 kL for 1 kL tanks to 110.9 ± 13 kL for 10 kL tanks. The relative efficiency of roof catchments in the city in comparison regional water supply catchments is an important consideration in understanding the regional benefits of domestic rainwater harvesting. A rainfall runoff curve for water supply catchments and residential roofs in Perth is shown in Figure 3.

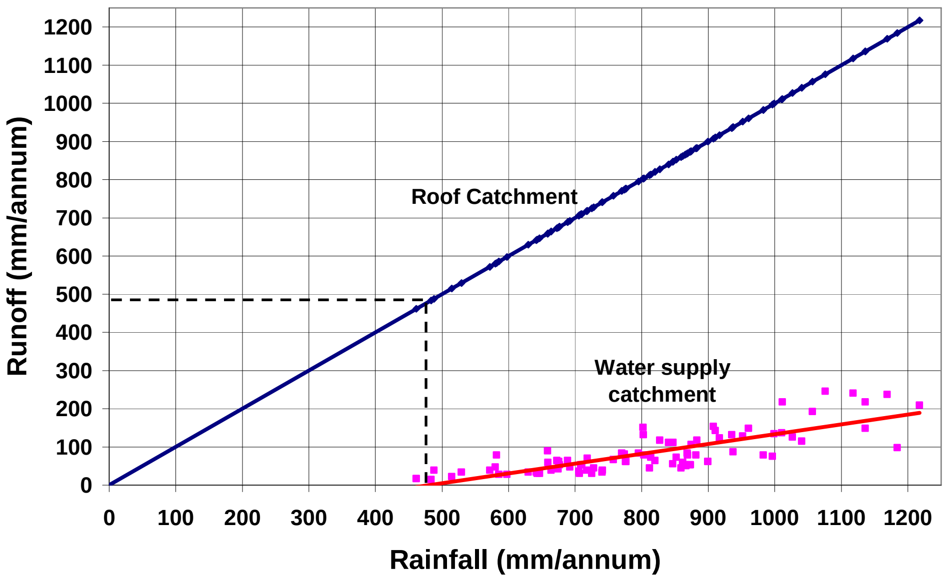

Figure 3: Harvest efficiencies of roof and regional water supply catchments for Perth

Figure 3 shows that the efficiency of the water supply catchments for Perth is considerably less than a roofed catchment feeding a rainwater tank. It is also shown that in dry years (rainfall < 500 mm) the annual runoff in water supply catchments is insignificant. In these years water losses to the soil and atmosphere accounts for most of the rainfall and water supplies are almost totally dependent on water stored in dams from more bountiful years and from aquifers. In contrast the roofed catchment, being impervious, only experiences a small loss at the commencement of each rain event and is able to harvest the majority of rainfall. As a result, a rainwater tank can harvest significant volumes of water even during drought years. Roofs are more efficient than water supply catchments for harvesting rainwater. This result also indicates that roof catchments in Perth will be more reliable than the regional water supply catchments in climate change scenarios. In addition to the greater efficiency of roof catchments in comparison to water supply catchments, it is often the case that roofs in major urban areas on the coastal fringe receive greater rainfall depths.

It is apparent that domestic rainwater tanks can make a significant contribution to the integrated water supply system for the Perth region. However, the water supply planning strategies for Perth are solely dependent on regional scale solutions and should also consider a range of decentralised strategies including water efficient appliances, reuse of treated wastewater, stormwater harvesting and rainwater harvesting. A range of authors estimate that over 100 GL of wastewater and more than 500 GL of stormwater is discharged, unused, to the ocean from Perth's urban areas in any year (ATSE, 2002; Water Corporation, 2002; PWUG, 2006). Note that the combined volumes of wastewater and stormwater discharges to the ocean are considerably in excess of the annual water demand for Perth. This discarded water can degrade the quality of receiving waters becoming an emerging environmental problem or this water can become an important water source for Perth.

The significant availability of unused local water supplies should be considered in the context of the status of the regional water supply. Let us consider that the inflow to regional water storages is currently about 167 GL/annum and assuming that the dams are normally less than half full; the average annual evaporation loss from the dams will be about 100 GL. Thus the average annual yield from the surface storages is estimated to be 67 GL. Assuming that water demand for Perth is currently 270 GL extractions from aquifers would be 203 GL.

As Perth's population grows, in accordance with current strategies, more water will need to be sourced from aquifers and desalination at a high environmental cost. Increased extraction from aquifers will have adverse impacts on wetlands and associated ecosystems whilst greater dependence on desalination will dramatically increase greenhouse gas emissions and impacts on ecosystems. In contrast, population growth in Perth will generate growing volumes of roof runoff, stormwater runoff and wastewater discharges that can be an important source of water. This study examines the potential contribution of rainwater tanks, water efficient appliances and wastewater reuse to the integrated water supply strategy in the Perth region.

METHOD

Lot scale analysis

The lot scale performance of rainwater tanks (1 to 10 kL), water efficient appliances and wastewater reuse (assuming 1 kL wastewater storage for each house) used in dual water supply schemes (rainwater and mains water) was continuously simulated using the PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) by Coombes and Kuczera (2001) at a range of locations across Perth including Perth Airport, Armadale, Midlands and Fremantle. The configuration of the rainwater tanks used in this study is shown in Figure 4.

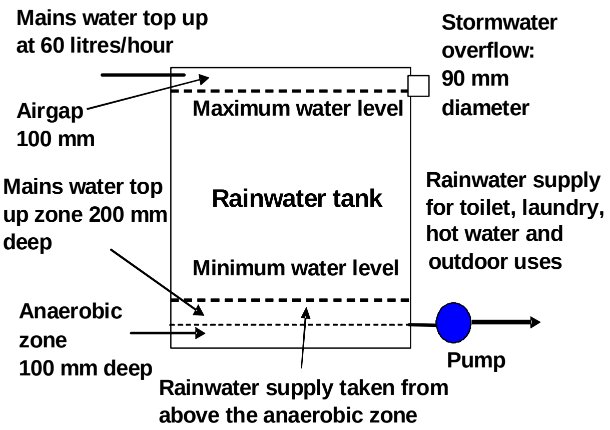

Figure 4: Configuration of rainwater tanks used in this study

Figure 4 shows that rainwater stored in the tank is used to supply domestic toilet, laundry, hot water and outdoor water uses. Runoff from roof surfaces with an area of 200 m^2 passes through a first flush device with a capacity of 20 litres and into the rainwater tank. Whenever water levels in the rainwater tanks are drawn below a depth of 300 mm, the tanks will be topped up with mains water at a rate of 60 litres/hour. Synthetic pluviograph rainfall (6 minute intervals) derived using the non-parametric nearest neighbourhood scheme by Coombes (2004) was used in the PURRS model. Synthetic pluviograph rainfall was developed for each location using the local daily rainfall and nearest available pluviograph records sourced from the Australian Bureau of Meteorology shown in Table 1.

Table 1: Australian Bureau of Meteorology daily and pluviograph rainfall records

Location	Station number	Start Date	End Date	Average Rainfall (mm/yr)	Years in record
Armadale	9001	1/1/1908	31/07/1999	868	92
Fremantle	9017	1/1/1908	31/12/1989	788	82
Midlands	9015	1/1/1915	31/12/1999	815	85
Perth Metro + Perth Airport	9225	1/1/1946	31/12/2000	811	55

The water use categories for Perth and the effectiveness of water efficient appliances used in this study are shown in Tables 2 and 3 respectively.

Table 2: Water use categories for Perth

Category	Proportion (%)
Drinking and Kitchen	8
Bathroom	18
Laundry	15
Toilet	10
Outdoor	49

Table 3: Impact of water efficient appliances

Product	Reduction in water use per product (%)
6/3 flush toilet	26
4A Washing Machine	50
3A showerheads	20
Tap regulator	2.1

Three scenarios are examined using the lot scale simulations including use of domestic rainwater tanks (RWT), use of domestic rainwater tanks and water efficient appliances (RWT+DM), and use of domestic rainwater tanks, water efficient appliances and wastewater reuse (RWT+DM+WW). In the RWT and RWT+DM scenarios rainwater is used to supplement mains water supplies for laundry, toilet and outdoor uses. The RWT+DM+WW scenario involves the use of rainwater for laundry and hot water uses with treated wastewater being used for toilet and outdoor uses. A 1 kL wastewater storage for each house in the RWT+DM+WW scenario that can represent a wide range of local strategies including household and estate scale wastewater reuse schemes. Note that the PURRS model employs climate and socio-economic water demand processes.

Regional analysis

Population data (ATSE, 2002) and information about regional water categories (Water Corporation, 2002) used in this study are shown in Tables 4 and 5 respectively.

Table 4: Regional water demand categories

Category	Proportion (%)
Perth residential	63
Other residential	4
Commercial	15
Industry	6
Agricultural	2
Mining	2
Unaccounted for	8

Table 5: Estimated population

Year	Population
2006	1,585,500
2010	1,687,200
2020	1,940,100
2030	2,175,200
2040	2,286,000
2050	2,529,600
2055	2,651,400

Daily water balance results from the PURRS model were compiled using historical climate data from each location into daily water use totals to create regional water demand Dem_t at time t as follows:

$$\mathrm{Dem}_t = \mathrm{Dwell}_t\{(1-\mathrm{Inst}_t)\mathrm{HW} + \mathrm{Inst}_t\mathrm{HT}\} + \mathrm{Other}_t \quad (1)$$

where $Dwell_t$ is the number of residential dwellings, $Inst_t$ is the cumulative number of households with rainwater tanks, water efficient appliances and wastewater reuse, HW is the water demand in households without alternative water sources, HT is the water demand in households with alternative water sources and $other_t$ is non-residential water demand.

Regional water security and requirement for augmentation of the regional water supply system was approximated using a simple annual water balance. It was assumed that 200 GL of water remained in storage at the commencement of the analysis, inflow to the dams was 67 GL/annum and a maximum of 200 GL can be sourced from aquifers. Augmentation of the system was undertaken whenever the combined storage in dams was drawn below 20% of total storage.

Analysis of regional economic impacts was undertaken by comparing the pumping, water treatment, operation and augmentation costs of business as usual (BAU) and alternative scenarios in a regional investment model. The scenarios that include alternative water sources also include a rebate at each household that will produce a similar economic outcome to the economic results of the BAU scenarios. The augmentation strategy will include the progressive installation of desalination plants with capacity to produce 45 GL/annum, operating costs of $450/ML and design lives of 20 years. In the regional investment analysis each scenario starts with enough funds to ensure economic viability of the strategy at the completion of the planning horizon. Each year expenses are deducted and interest is earned or paid on the balance. In the year the water supply system requires augmentation the cost of augmentation is deducted from the balance of the initial investment. For the BAU and rainwater tanks scenarios, the balance of the initial investment carried forward from year t, Bal_{t+1}, is:

$$Bal_{t+1} = (1 + Rint)(Bal_t - (PumpCost - WTCost - MaintCost)Dem_t - augCost - Rebate.Tint_t) \quad (2)$$

where Rint is the real interest rate, PumpCost is pumping cost, WTCost is the cost of water treatment, OpCost is the operation costs, rebate is the sum of rebates paid to householders for installation of a rainwater tanks, $Tint_t$ is the installation of rainwater tanks and augCost is the augmentation cost for the traditional water supply (if any) in year t.

The real interest rate is the Reserve Bank interest rate less the inflation rate. For the purposes of this study the real interest rate was conservatively assumed to be 5%. The assumed costs to operate the regional water supply system are: pumping $140/ML, water treatment $85/ML and other operating costs $450/ML (not administration costs). The change ΔGH in CO_2 or greenhouse gas emissions from the regional water systems was defined as:

$$\Delta GH = \sum_{t=2054}^{t=2005} \left(RD_t^R.GH + 0.71.Tint_t.HT_t.222 - RD_t^{BAU}.GH \right) \quad (3)$$

where RD_t^R is regional water demand with rainwater tanks (ML), GH is the greenhouse gas emissions (kg/ML) and RD_t^{BAU} is regional water demand without rainwater tanks (ML).

As shown in Equation 3, the analysis considers the cumulative change in greenhouse gas emissions from the regional water supply strategies over a 50 year period. The small pumps delivering rainwater and wastewater to the households were assumed to consume 250 kWh of electricity for each ML of rainwater supply. Generation of a kWh of electricity was assumed to create a 0.89 kg of CO_2. The CO_2 emissions from operation of the regional water system were estimated to be 840 kg/ML and the emissions from desalination of seawater is 4,390 kg/ML.

RESULTS AND DISCUSSION

The household water balance and mains water savings at the Perth Airport area for households with 3 occupants are shown in Figures 5 and 6 respectively.

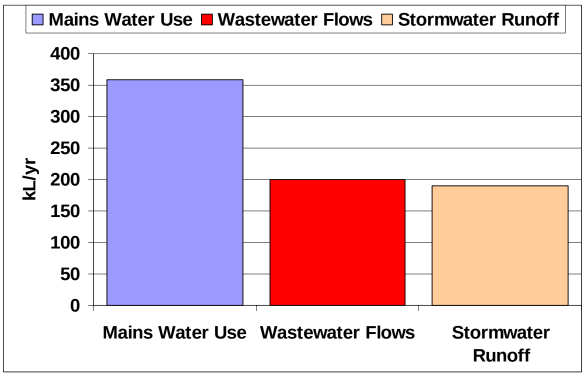

Figure 5: Water balance at Perth Airport

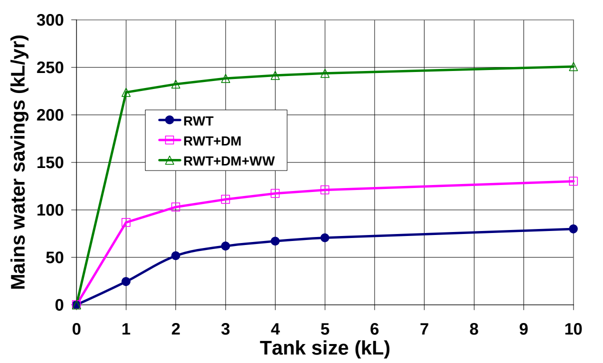

Figure 6: Mains water savings at Perth Airport

Figure 5 reveals that the average annual mains water demand, wastewater discharge and stormwater runoff from the allotment with a 3 person household was 359 kL, 200 kL and 190 kL respectively. The combined volumes of wastewater and stormwater of 390 kL are greater than the volume of water demand. Thus the availability of local or decentralised water sources is greater than the household demand for water. The results from the Armadale, Fremantle, Midlands and Perth Airport are similar.

Figure 6 shows that the RWT strategy reduces average annual mains water use by 24 kL for a 1 kL rainwater tank to 80 kL for a 10 kL tank. The optimum sized rainwater tank was observed to be a 3 kL tank that provided average annual mains water savings of 62 kL and the use of water efficient appliances produced average annual mains water savings of 50 kL. Average annual mains water savings from the RWT+DM+WW strategy ranged from 224 kL to 251 kL. Adopting 3 kL rainwater tanks as the optimum size the reductions in mains water use for the RWT, RWT+DM and RWT+DM+WW strategies are 17%, 31% and 65%.

The reductions in stormwater runoff volumes resulting from the use of rainwater tanks is shown in Figure 7. Figure 7 reveals that rainwater tanks will stormwater runoff volumes from 20% for 1 kL tanks to 43% for 10 kL tanks. This result indicates that the use of rainwater tanks will also provide mitigation of minor flood events and improvements in urban stormwater quality.

The RWT+DM+WW strategy will also reduce wastewater discharges by 90%.

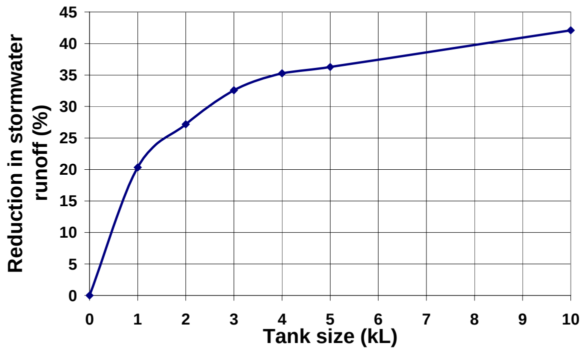

Figure 7: Reduction in stormwater runoff

The impact of adopting the RWT, RWT+DM and RWT+DM+WW strategies that are based on 3 kL rainwater tanks for all new housing is shown in Figure 8.

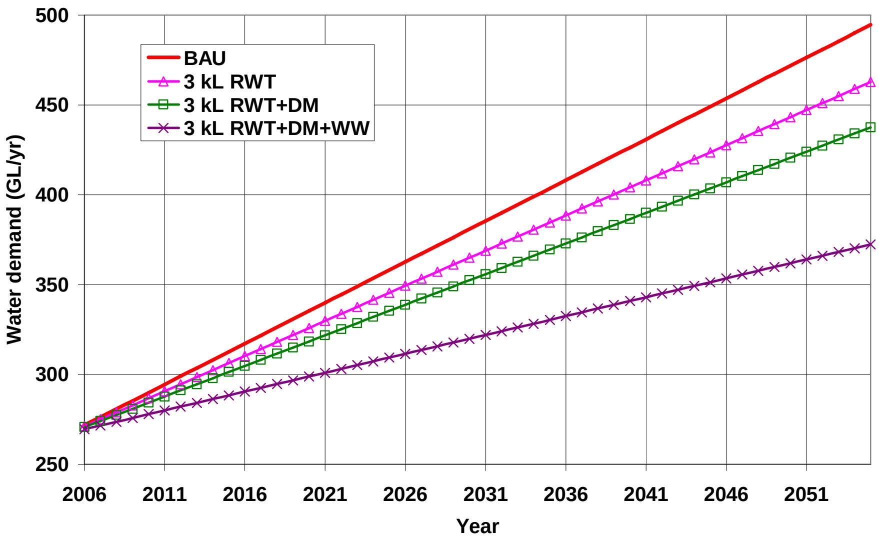

Figure 8: Water savings resulting from installation of decentralised solutions to new housing

Figure 8 reveals that installation of decentralised water solutions for new housing will have considerable impact on reducing growth in water demands for the Perth region. At the end of the planning horizon considered by this study, in the year 2055, the RWT, RWT+DM and RWT+DM+WW strategies will reduce regional water demand by 29 GL/annum (6%), 52 GL/annum (11%) and 113 GL/annum (24%) respectively. The impact of adopting the RWT,

RWT+DM and RWT+DM+WW strategies for all new housing and 1% per annum of existing housing is shown in Figure 9.

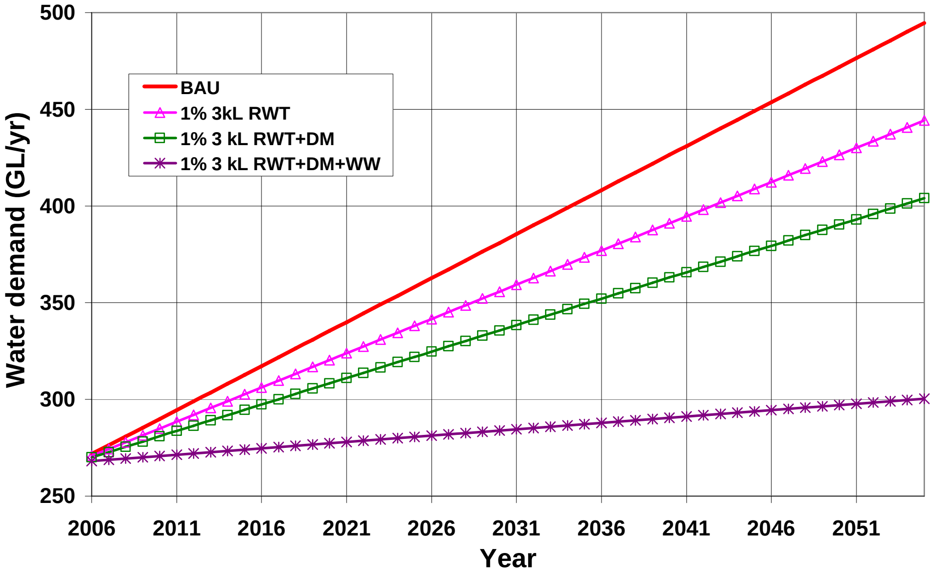

Figure 9: Water savings resulting from installation of decentralised solutions to new housing and 1% of existing housing per annum

Figure 9 shows that in 2055 the RWT, RWT+DM and RWT+DM+WW strategies will reduce regional water demand by 46 GL/annum (10%), 83 GL/annum (17%) and 179 GL/annum (37%). This scenario could represent a strategy that targets all new and redeveloped housing. The impact of adopting the RWT, RWT+DM and RWT+DM+WW strategies for all new housing and 2% per annum of existing housing is shown in Figure 10.

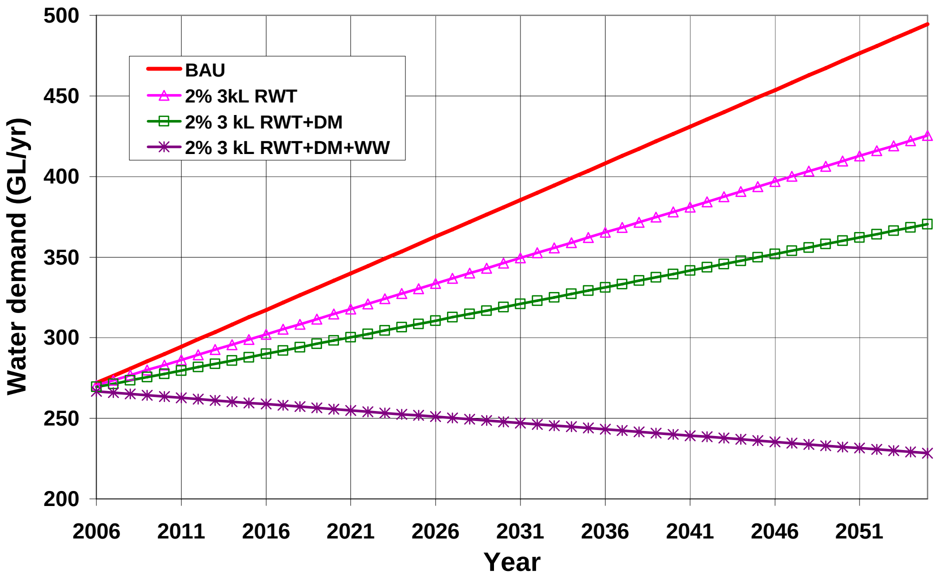

Figure 10: Water savings resulting from installation of decentralised solutions to new housing and 2% of existing housing per annum

Figure 10 shows that in 2055 the RWT, RWT+DM and RWT+DM+WW strategies will reduce regional water demand by 64 GL/annum (13%), 114 GL/annum (24%) and 245 GL/annum (51%). This scenario represents an incremental approach to full adoption of each strategy by 2055 and represents the full potential of the strategies with respect to housing in Perth. The addition of schemes to target commercial, industrial and unaccounted for water demands will increase the regional impacts of these strategies.

The analysis of regional water security included the proposed desalination plant at Kwinana (capacity of 45 GL/annum) and assumed that augmentation of the system was required when regional water storages were drawn down below 20%. Impacts of adopting decentralised water management strategies on regional water security are shown in Table 6.

Table 6: Augmentation timing for the regional water supply system

Scenario	Augmentation timing (year)			
	BAU	RWT	RWT+DM	RWT+DM+WW
BAU	2041, 2052			
New houses		2047	2053	>2055
New + 1% houses		2052	>2055	>2055
New + 2% houses		>2055	>2055	>2055

Table 6 shows that the Business As Usual (BAU) scenario required the construction of two additional desalination plants in the years 2041 and 2052. The RWT and RWT+DM strategies for new housing require a single augmentation in the years 2047 and 2053 respectively whilst the RWT strategy for 1% of existing and all new houses required a single augmentation in 2052. All of the strategies produced significant improvements in regional water security with the RWT+DM and RWT+DM+WW strategies providing considerable impact.

The economic benefits to the operation of the regional water supply system for each house with an alternative water management strategy are shown in Table 7.

Table 7: Regional economic benefits for each house with alternative water supply

Scenario	Benefit ($/house)		
	RWT	RWT+DM	RWT+DM+WW
New houses	1,098	1,732	3,403
New + 1% houses	984	1,716	3,109
New + 2% houses	113	171	322

Table 7 reveals that the economic benefits for each house installing a decentralised water management system range from $113/house to $3,403/house. The results show that the optimum scenarios appear to be RWT+DM and RWT+DM+WW strategies for all new houses or for 1% of existing and all new houses. Note that the benefits of these strategies are most likely under-estimated because the impacts on provision of estate and catchment scale water, sewage and stormwater infrastructure have not been considered. The changes in greenhouse gas emissions from the operation of the regional water supply system with alternative water management strategies are shown in Table 8.

Table 8: Change in greenhouse gas emissions for each scenario

Scenario	Change in greenhouse gas emissions (%)		
	RWT	RWT+DM	RWT+DM+WW
New houses	-7	-15	-35
New + 1% houses	-12	-24	-56
New + 2% houses	+24	+7	-24

Table 8 shows that the decentralised water management strategies produce considerable reductions in regional greenhouse gas emissions with the exception of the RWT and RWT+DM scenarios in the strategy for 2% of existing and all new houses. The strategy installing decentralised water management at 1% of existing and all new houses appears to be optimum. Nevertheless, these results are likely to be conservative because it was assumed that all hot water, laundry, toilet and outdoor use were supplied by a local pump, even when rainwater was not available. Clearly the installation of a mains water bypass arrangement will minimise use of local pumps.

CONCLUSIONS

A preliminary study of the impact of including decentralised rainwater harvesting, water efficient appliances and wastewater reuse strategies in analysis of the operation of regional water supply systems reveals considerable benefits for Perth. These strategies provide significant reduction in regional water demand, improvement in regional water security, decreases in greenhouse gas emissions and economic benefits. A compelling case has been made for the inclusion of decentralised water management options in analysis of regional water systems. This is a contrast to the normal practice of uncritical dismissal of decentralised options prior to detailed systems analysis. The results indicate that adoption of 3 kL rainwater tanks for hot water and laundry uses, water efficient appliances and estate scale wastewater reuse for outdoor and toilet uses for all new housing, and 3 kL tanks for laundry, toilet and outdoor uses with water efficient appliances at a rate of 1% per annum to existing houses may be optimum.

In any event, the results of this analysis are conservative and most likely under-estimate the benefits of decentralised water management strategies because the estate and catchment scale impacts of reducing water demands, sewerage discharges and stormwater runoff on the provision of infrastructure have not been considered. The costs of providing the decentralised solutions have not been included. In addition, this study has relied on data from other locations in some situations to complete the analysis. Importantly, this study has also not attempted to determine the true value to society and ecosystems of increased water security, reduced greenhouse gas emissions and decreased discharges of sewage and stormwater in future decades. These important outcomes, as demonstrated in this study, cannot be dismissed using today's values in a narrow economic perspective.

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