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Energy and economic impacts of rainwater tanks in urban areas on the operation of regional water systems

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Abstract: This study has analysed the reductions in operational costs and greenhouse gas emissions from regional water supplies that include installation of rainwater tanks used to supply domestic laundry, toilet and outdoor water uses across New South Wales. A considerable reduction in operating costs and greenhouse gas emissions of regional water supplies was observed. In addition, significant improvement in the security of regional water supplies was observed for coastal regions. These benefits were seen to be dependent on the average annual rainfall depth, distance from the coast, and availability of reliable operational and augmentation data of a regional water system. This study reveals the importance of including rainwater tanks in analysis of the operation of regional water supplies.

Keywords: Rainwater tanks, regional water security, operational costs, greenhouse gas emissions

1. INTRODUCTION

Water utilities and local councils throughout New South Wales are encouraging the use of rainwater tanks to supplement mains water supplies and to manage urban stormwater runoff. Although rainwater tanks are widely used in Australia, little is known about the efficacy of rainwater tanks as a means to improve the security of water supplies and to reduce the operating costs and energy use of regional water supplies. As a consequence the operational and economic benefits derived from the use of rainwater tanks are poorly understood. Previous studies by Coombes et al. (2002; 2003) have examined the impacts of the widespread installation of rainwater tanks on regional water security and economics for the Central Coast, Newcastle and Sydney regions of New South Wales (NSW).

The performance of rainwater tanks used in dual water supply schemes (rainwater and mains water) was shown to vary considerably across NSW by Coombes and Kozarovski (2005). This study builds on the previous research and aims to develop an understanding of the impacts of rainwater tanks on reducing the operating costs and energy consumption of regional water supplies throughout regional NSW. The performance of rainwater tanks was subject to detailed analysis at twelve locations that were considered representative of the climatic and spatial variation across NSW, namely: Broken Hill, Central Coast, Eurobodalla, Deniliquin, Kempsey, Hastings, Mudgee, Newcastle, Narrabri, Parkes, Sydney and Tweed Heads.

This paper presents a preliminary regional scale analysis conducted to understand the impacts of rainwater tanks on regional water security, replacement of water treatment and transfer infrastructure, operating costs and greenhouse gas emissions. A single alternative scenario is discussed that involves installation of rainwater tanks to all new houses and to 2% of existing houses per year. Household water demand results from previous studies were combined with regional scale results from this study in an economic analysis to provide additional insight into the benefits to the community of installing rainwater tanks.

2. METHOD

This study builds on the regional analysis of the lot scale performance of rainwater tanks reported by Coombes and Kozarovski (2005) to investigate regional economic and greenhouse gas emissions impacts across New South Wales. The investigations by Coombes et al. (2002; 2003) into the impacts of the widespread adoption of rainwater tanks on water security in the Lower Hunter, Central Coast and Sydney regions are also incorporated in this study.

Recent data provided by the NSW Department of Energy, Utilities and Sustainability (DEUS, 2005) and annual reports from water utilities (HWC, 2005; SWC, 2005) on the energy use, operating, pumping, augmentation and water treatment costs of regional water networks was utilised in this study (Table 1).

Information about augmentation options for the Central Coast, Newcastle and Sydney regions from Coombes et al. (2002; 2003) was adopted for this study. Augmentation details were not available for Hastings, Mudgee and Narrabri.

Table 1: Characteristics of regional water supply systems at locations across New South Wales

Location	Use (kL/hh/yr)	Rain (mm/yr)	Price ($/kL)	CO_2 (kg/ML)	Pump ($/ML)	Treat ($/ML)	Operation ($/ML)	Augment ($m)
Broken Hill	323	258	0.65	3,050	320	449	1163	NA
Central Coast	193	1,276*	0.925	611	70	72	889	76, 195
Deniliquin	696	410	0.15	109	20	119	120	NA
Eurobodalla	193	974	1.00	1,134	130	7	625	75, 42
Hastings	200	1,387	0.93	589	140	44	776	22
Kempsey	197	1,234	0.83	855	100	85	470	NA
Mudgee	281	671	0.90	839	190	3	433	NA
Narrabri	561	639	0.33	540	60	6	128	NA
Newcastle	212	982*	1.09	374	70	230	426	104, 102
Parkes	378	589	0.29	3,208	160	58	774	32
Sydney	292	900*	1.264	232 4,390**	70	230	440	2000
Tweed Heads	219	1,663	0.62	687	60	70	368	NA

* Average results for the water supply zones in the Sydney, Newcastle and Central coast regions
** The augmentation option for Sydney was assessed as a desalination plant

The energy use, and pumping, water treatment and augmentation costs for the Central Coast, Newcastle and Sydney were estimated from the utilities' annual reports and previous studies by Coombes et al. (2002; 2003). Note that two staged augmentations are planned for some locations.

This study compares the operational impacts on regional water systems of a single scenario that includes rainwater tanks to a business as usual (BAU) scenario that does not include the impacts of rainwater tanks in analysis of the performance of the regional water network. It was assumed that rainwater tanks were installed at all new houses and 2% of existing houses in any year. Lot scale results for houses with and without rainwater tanks were incorporated in regional water demands that were used within water supply headworks models.

2.1 Lot scale analysis

The lot scale performance of rainwater tanks used in dual water supply schemes (rainwater and mains water) was continuously simulated using the PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) at a range of locations across New South Wales. Details of these lot scale investigations are presented by Coombes et al., (2002; 2003) and Coombes and Kozarovski (2005). Times series data from these studies including climate, mains water demands and yields from rainwater tanks are utilised in this study. The configuration of the rainwater tanks used in this study is shown in Figure 1.

Figure 1 shows that rainwater stored in the tank is used to supply domestic toilet, laundry and outdoor water uses. Runoff from roof surfaces 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 40 litres/hour.

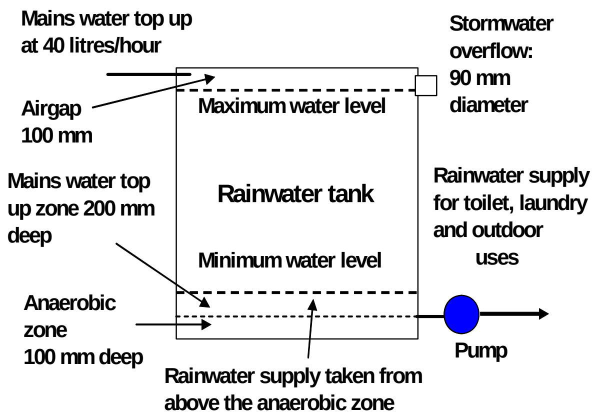

Figure 1: Configuration of rainwater tank

2.2 Analysis of regional water security and water demands

Daily water balance results from the PURRS model were compiled using historical climate data from each region into daily water use totals and daily rain depth, count of days since the last day with rainfall and average daily maximum ambient air temperature to create resource files of water demand. Resource files were also created for water demands from households with rainwater tanks. The method of non-parametric aggregation created by Coombes et al. (2002) was used to generate daily domestic water use for each dwelling using the historical resource files and climate data. Water demand Dem_t at time t was derived as:

$$\mathrm{Dem}_t = \mathrm{Dwell}_t \begin{Bmatrix} (1-\mathrm{Inst}_t)\mathrm{HW} + \\ \mathrm{Inst}_t \mathrm{HT} \end{Bmatrix} + \mathrm{Other}_t \qquad (1)$$

where $Dwell_t$ is the number of residential dwellings, $Inst_t$ is the cumulative number of installed rainwater tanks and $other_t$ is non-residential water demand at time t.

Population data and information about regional water systems used in this study was sourced from the Australian Bureau of Statistics, Planning NSW and the NSW Department of Energy, Utilities and Sustainability (Table 2).

Table 2: Regional population and water use characteristics

Location	Pop (1000)	Houses (1000)	Use (%)	Growth (%/yr)
Broken Hill	22	8	45	0
Central Coast	289	124	62	1.4
Deniliquin	8	3	66	0
Euro' alla	33	18	75	1.1
Hastings	64	25	75	0.9
Kempsey	24.3	11	57	1.7
Mudgee	10.2	4.7	58	1
Newcastle	475	170	49	0.9
Narrabri	10.8	4.4	66	0
Parkes	11.5	5.5	28	0.2
Sydney	4227	1253	70	0.75
Tweed Heads	68.7	26.7	70	1.7

The values Use and Growth in Table 2 refer to the residential proportion of total water demand and the population growth rate respectively.

Non-residential water demand was estimated to be a proportion of total water demand at each location in accordance with ratios provided by DEUS (2005). Sufficient data was available to calibrate regional water demands calculated using Equation 1 at Broken Hill, Central Coast, Deniliquin, Eurobodalla, Kempsey, Newcastle, Parkes and Sydney. At these locations the performance of the water supply headworks systems was simulated using the WATHNET network linear program for headworks simulation by Kuczera (1992). In this study reliability is defined as the probability that water shortages will not be experienced in a particular year. Failures in reliability were considered to be a 10% annual probability or a 5% daily probability of water shortages.

WATHNET was used to generate 1000 replicates of climate and streamflow variables for the urban and water supply catchments. At each time step climate variables in the headworks model are used to find matching climate variables and coincident daily water use results.

There was insufficient data available to calibrate regional water demands or to evaluate regional water security at Hastings, Mudgee, Narrabri and Tweed Heads. At these locations the regional economic and greenhouse gas emissions impacts were determined using the reductions in regional water demands created by installation of rainwater tanks.

2.3 Analysis of regional economics

Analysis of regional economic impacts was undertaken by comparing the pumping, water treatment, operation and augmentation costs of business as usual (BAU) and rainwater tank scenarios in a regional investment model. The scenarios that include rainwater tanks also include a rebate for installation of rainwater tanks at each location that will produce a similar economic outcome to the economic results of the BAU scenarios. In this study augmentation of the water supply system includes the requirement for pumps, pipes, reservoirs, water treatment plants and dams.

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:

$$\begin{aligned} \mathrm{Bal}_{t+1} = (1+\mathrm{Rint})(\mathrm{Bal}_t - (\mathrm{PumpCost} \\ - \mathrm{WTCost} - \mathrm{MaintCost})\mathrm{Dem}_t \\ - \mathrm{augCost} - \mathrm{Rebate.Tint}_t) \end{aligned} \quad (2)$$

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%.

2.4 Analysis of greenhouse gas emissions

The change ΔGH in CO_2 or greenhouse gas emissions from the operation of regional water systems was defined as:

$$\Delta \mathrm{GH} = \sum_{t=2054}^{t=2005} \begin{pmatrix} \mathrm{RD}_t^{R}.\mathrm{GH} + 0.71.\mathrm{Tint}_t.\mathrm{HT}_t.222 \\ - \mathrm{RD}_t^{\mathbf{BAU}}.\mathrm{GH} \end{pmatrix} \quad (3)$$

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 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 0.89 kg of CO_2.

3. Results

Average annual mains water savings for selected tank sizes at each location are shown in Figure 2. Significant average annual mains water savings from the use of rainwater tanks was established at most of the locations analysed in this study. At each location, 3 kL rainwater tanks were shown to produce a significant proportion of the annual average mains water savings. Increases in average annual mains water savings was seen to diminish with increases in tank size above the selection of a 3 kL rainwater tank.

Use of rainwater tanks in areas with high rainfall such as Tweed Heads, Hastings, Central Coast, Newcastle and Kempsey produces the largest average annual mains water savings. Whilst areas with low rainfall such as Broken Hill and Deniliquin provide the lowest average annual mains water savings from the use of rainwater tanks. Interestingly rainwater tanks at inland areas such as Mudgee, Parkes and Narrabri with moderate rainfall depths (about 600 mm/yr) and higher water demands provided similar average annual mains water savings to Eurobodalla that has a higher rainfall depth (about 1000 mm/yr). Yields from the rainwater tanks are also dependent on the magnitude of water demand sourced from the tanks. The impact of the installation of rainwater tanks on the scheduling of regional water supply augmentation is shown in Table 3.

Table 3: Augmentation timing for the regional water supply systems

Location	BAU	Rainwater tank scenario			
		1 kL	3kL	5 kL	10 kL
Broken Hill	NR	NR	NR	NR	NR
C' Coast	2026	NA	NA	NA	>2054
Deniliquin	NR	NR	NR	NR	NR
Euro'alla	2007 2008	2008 2027	2008 >2054	2008 >2054	2008 >2054
Kempsey	2038	2048	>2054	>2054	>2054
New' tle	2041	NA	NA	NA	>2054
Parkes	2013	2013	2013	2013	2013
Sydney	2025	NA	NA	>2054	NA

*NR denotes that augmentation was not required and NA indicates that data was not available to determine augmentation timing.

Table 3 shows that installation of rainwater tanks resulted in significant deferral of the requirement to augment regional water systems in the coastal regions of Central Coast, Eurobodalla, Kempsey, Newcastle and Sydney.

Installation of rainwater tanks in the inland regions of Broken Hill, Deniliquin and Parkes did not result in deferral of the requirement to augment regional water supply systems. However, it is noted that many inland urban areas including Broken Hill and Deniliquin source water from regional irrigation supplies and that insufficient data was available to determine the augmentation strategies for the remaining regions.

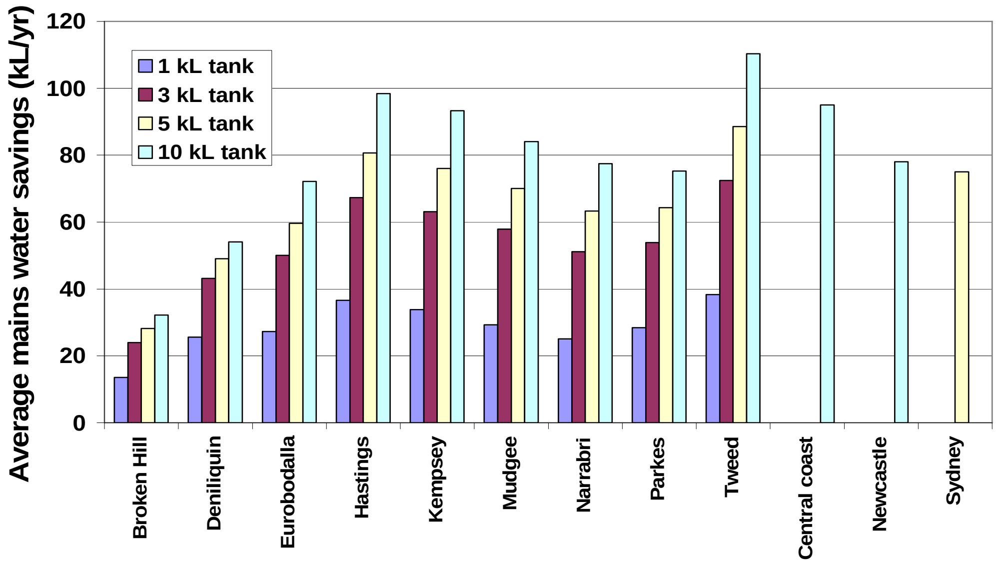

Figure 2: Average annual mains water savings at each location

The economic benefits for each house that install a rainwater tank to the regional water supply system was derived from reduced water treatment, pumping, operating and augmentation costs. Figure 3 reveals the value of a rebate for each household that installs a rainwater tank that will not increase the overall operating costs of the regional water supply in comparison to the BAU scenario. This represents the present value of reductions in operating costs of the regional water supply systems for each household that installs a rainwater tank during the 50 year planning horizon.

The reduction in operating costs for each household installing rainwater tanks was observed to occur in four regional bands. The lowest benefits ranging from $57 to $258 per rainwater tank was determined for the inland areas of Broken Hill, Deniliquin and Narrabri. A small benefit was expected for low rainfall areas such as Broken Hill and Deniliquin that experience average annual rainfall depths of less than 410 mm. However, the benefit calculated for Narrabri with an average annual rainfall depth of 639 mm is seen to be influenced by the low operation costs.

A medium level of benefits ranging from $150 to $890 per rainwater tank was determined for Mudgee, Parkes and Tweed Heads that experience average annual rainfall of 589 mm to 1,663 mm. The lower benefits at tweed Heads are explained by the low operational costs and unavailable augmentation data. A higher level of benefits ranging from $565 to $2,102 was calculated for Central Coast, Hastings, Kempsey and Newcastle with average annual rainfall depths from 982 mm to 1,387 mm. All of these locations are on the coast and experience higher average annual rainfall depths.

The highest level of benefits ranging from $2,575 to $6,100 determined for Eurobodalla and Sydney that are subject to average annual rainfall depths of 900 mm and 974 mm. Higher benefits at these locations may be due to the detailed nature of the augmentation data available for this study. Determination of the benefits of rainwater tanks for reducing operational costs of regional water supply systems is dependent on average annual rainfall depth, distance from the coast, and availability of reliable operational and augmentation costs.

Figure 4 reveals significant reductions in greenhouse gas emissions from the operation of the rainwater tank scenario for regional water systems adjacent to the coast. Considerable reductions in greenhouse gas emissions were calculated for both the Eurobodalla and Sydney regions that resulted from a reduced dependence on pumping from river systems and desalination plants respectively. The use of 1 kL rainwater tanks at Hastings and Tweed heads resulted in small increases in greenhouse gas emissions.

The inland regions of Broken Hill, Mudgee and Parkes showed decreases or insignificant increases in greenhouse gas emissions. A 1 kL rainwater tank installed in the Mudgee region may result in a small increase in greenhouse gas emissions. The reductions in greenhouse gas emissions at Broken Hill that has a low average annual rainfall was attributed to the regions dependence on a desalination plant to reduce the salinity of regional water supply.

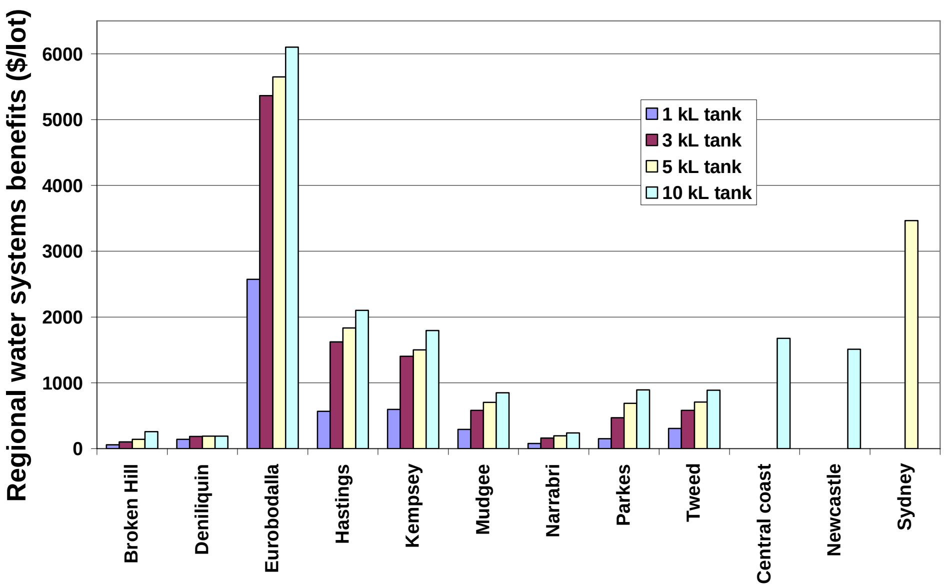

Figure 3: Economic benefits to regional water systems from installation of rainwater tanks

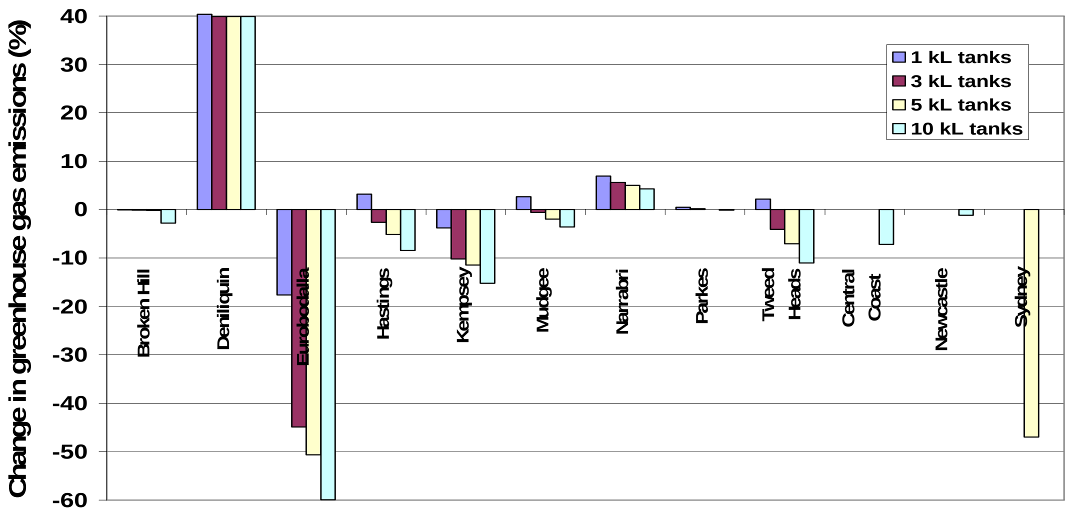

Figure 4: Change in greenhouse gas emissions from regional water supply in each region

Installation of rainwater tanks at Deniliquin and Narrabri was seen to produce significant increases in greenhouse gas emissions. The considerable increase in greenhouse gas emissions at Deniliquin is due to the reported low energy use of the regional water supply, insufficient annual average rainfall and high household water demands. Increases in greenhouse gas emissions from the rainwater strategy at Narrabri are due to the high household water demands.

Note that use of mains water to top up the rainwater tank results in the entire laundry, toilet and outdoor water demands being supplied by the household pump regardless of the availability of rainwater. At inland regions with relatively low average annual rainfall depths the use of a mains water bypass arrangement would ensure that only rainwater is pumped into the house thereby significantly reducing energy use.

4 CONCLUSIONS

This preliminary study has revealed that the widespread installation of rainwater tanks used to supplement mains water supplies for domestic laundry, toilet and outdoor uses can produce considerable reductions in operating costs and greenhouse gas emissions of regional water supplies.

A considerable improvement in the security of regional water supplies was also observed for coastal regions. These benefits are dependent on the average annual rainfall depth, distance from the coast, and availability of reliable operational and augmentation data of a regional water system. The widespread use of rainwater tanks reduces the energy use for operating regional water supplies and associated greenhouse gas emissions by reducing dependence on pumping from water sources, water treatment and desalination.

The results of this study may be subject to some uncertainty because only a single rainwater scenario is presented, all domestic laundry, toilet and outdoor water demand was assumed to be supplied via household pumps regardless of the availability of rainwater, the energy consumption from household pumps could vary from the assumptions in this study and data from some regions was not available. Nevertheless, this study reveals the importance of including rainwater tanks in analysis of the operation of regional water supplies.

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