ECONOMIC, WATER QUANTITY AND QUALITY IMPACTS FROM THE USE OF A RAINWATER TANK IN THE INNER CITY

Peter J. Coombes[1], George Kuczera[2] and Jetse D. Kalma[3]
[1]Research Fellow, University of Newcastle, Callaghan, NSW, Australia
[2]Associate Professor, University of Newcastle, Callaghan, NSW, Australia
[3]Professor, University of Newcastle, Callaghan, NSW, Australia

Abstract

A dual water supply system (rainwater and mains water) has been installed at an old house in Maryville a inner city suburb of Newcastle in New South Wales, Australia. A design was developed for the installation of a rainwater tank to supply rainwater for toilet, hot water and outdoor uses. The rainwater supply is supplemented with mains water via a trickle top up system when water levels are low in the tank. An air gap is used for backflow prevention in accordance with Australian standards. The design, construction and performance of the dual water supply system at the Maryville house are examined in this paper. Monitoring of water quality from the rainwater tank and from an instantaneous hot water service at the Maryville house has revealed that the rainwater was acceptable for hot water, toilet and outdoor uses. Rainwater used in the hot water service was compliant with Australian drinking water standards. The cost of rainwater has been found to be $0.3 per kL which is less than the price of mains water in the Lower Hunter region and the commonly assumed cost of $1 to $14 per kL.

Key Words: rainwater tank, dual water supply, bacteria, chemicals, costs

Introduction

An old house in Maryville, an inner city suburb of Newcastle in New South Wales, Australia was fitted with an above ground 9,060 Litre Aquaplate rainwater tank (area is 3.754 m^2 and height is 2.415 m) to supply hot water, toilet and outdoor uses. The house is adjacent to Newcastle's heavy industrial area and the Industrial Highway and is situated on level ground consisting of silty-sand soil. It has a rusty galvanised iron roof with an area of 135 m^2 and the allotment area is 245 m^2. An instantaneous gas hot water service set at 55°C is used to deliver hot water to the household that consists of an average of three people. During the working week two university students and their guests occupy the house. On weekends the house usually has four occupants (the parents of the students stay at the house on weekends). A monitoring program was established to observe water quality in the rainwater tank and at the household taps, and water use.

This paper discusses the design, approval process, performance and costs of the dual water supply system. Water quantity and quality results from the monitoring program are also presented.

Design of the Dual Water Supply System

The dual water supply system and the locations of monitoring devices at the Maryville house are shown in Figure 1. In the design rainfall from a portion of the roof with an area of 115 m^2 is directed to the rainwater tank and supplied via a small pump directly to the hot water service and the toilet cistern. To eliminate the possibility of cross connection between the rainwater and mains water supplies the rainwater supply has been directly connected to the hot water service and the toilet cistern. Rainwater for outdoor uses is drawn directly from the rainwater tank and from mains water supply. Mains water is supplied to the remainder of the house and is used to top up the rainwater tank when water levels are low (Figure 1).

The configuration of the rainwater tank in the dual water supply system is shown in Figure 2. When tank water levels are low, such as during hot, dry periods, the tank is topped up with mains water via a trickle system. The trickle top up system is expected to reduce the daily peak demand on the mains water distribution network. In the event of pump or power failure the rainwater tank can be bypassed. Design of the rainwater reuse scheme (Figures 1 and 2) makes provision for:

- a minimum storage volume (to ensure that water supply is always available)
- a rainwater storage volume and
- an air space for additional stormwater management.

The minimum storage volume should be set at the maximum daily water use that is expected from the tank less the potential daily mains water top up volume. However the minimum storage volume for the Maryville rainwater tank has been arbitrarily set at 1,185 litres (a depth of 0.5 m). If the volume of stored water falls below the minimum storage volume, the shortfall is overcome by trickle topping up the tank with mains water to the required level. A simple float valve system was installed to do this automatically.

The rainwater storage volume is the total volume available in the tank to store rainwater below the overflow pipe. The rainwater storage volume is 8,315 litres (a depth of 2.215 m). The air space between the overflow pipe and the top of the tank can be used to provide 'stormwater detention', thereby delaying the delivery of excess roof water to the drainage system and to prevent cross connection between the rainwater and mains water supplies. The height of the airspace provided was 0.2 m corresponding to an airspace volume of 0.75 m^3. Rainwater is drawn from the tank via the pump at a point 0.1 m above the base of the tank to avoid entraining sediment from the base of the tank into the rainwater supply

Installation of the rainwater tank involved the following steps. The ground surface at the location chosen for the tank was levelled and a 100 mm thick reinforced concrete slab constructed. After the concrete had set the tank was placed on the slab with the tap, overflow pipe and outlet pipe orientated in the desired directions. A plumber was commissioned to install the pump, pipes from the roof gutters and water supply pipes to the toilets and hot water systems. The plumber also installed the mains water trickle top up and float system. An electrician was used to install a power point close to the pump.

The Approval Process

A development that installs a rainwater tank with a capacity less than 5,000 Litres does not require a development application in accordance with Newcastle City Council's (NCC) exempt development provisions. It was intended to install a rainwater tank with a capacity of 9,060 Litres at the Maryville house therefore a development application was required.

The development application was submitted to NCC on the 30/09/1999 and approval for the installation of the rainwater tank was provided on the 14/12/1999 subject to certain conditions. NCC required that the Hunter Water Corporation (HWC) approve the dual water supply system and that a program to monitor water quality be established to ensure that the rainwater tank provided acceptable water quality.

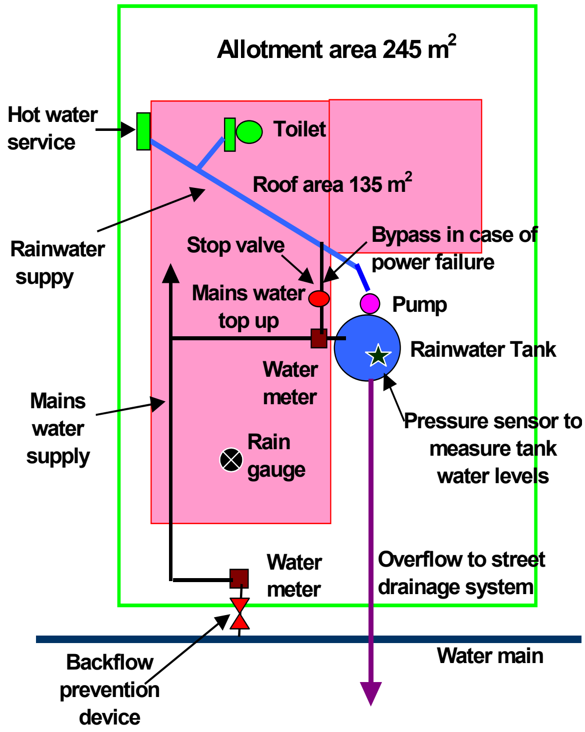

Figure 1: Schematic of the dual water supply system

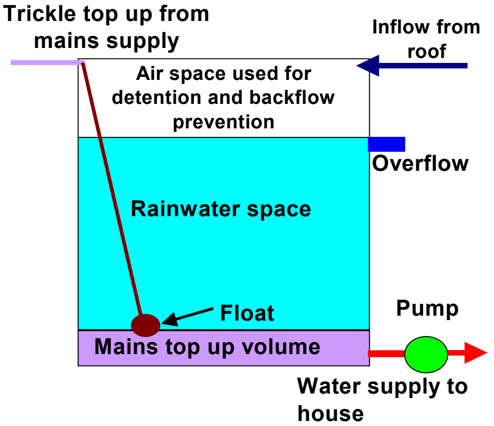

Figure 2: Elevation view of the rainwater tank

Even though the dual water supply system was approved by the HWC [B. Peterson, personal communication, 1999] there was concern about the reuse of rainwater for any purpose at NCC [N. Roser, personal communication, 1999]. The development approval was delayed until an undertaking was given to monitor the quality of water from the rainwater tank.

Monitoring Results

The dual water supply system was installed at the Maryville house during August 1999 and use of the system commenced during October 2000. To facilitate measurement of the water balance at the rainwater tank a meter was placed on the mains water top up pipe, a rain gauge has been located on the house roof and a pressure sensor was used to record water levels in the rainwater tank. The observations from these devices have been combined with readings from the meter on the mains water supply to the house and HWC records to determine water use. The monitoring scheme for the rainwater tank with mains water top up system is shown in Figure 1. A manual monitoring program to collect and analyse water samples and to read meters commenced in August 1999. The automated monitoring program to measure rainfall and water levels in the tank commenced on the 15/12/2000. This section reports the water quantity and quality results.

Water Quantity

The quantity of rainwater and mains water used was derived from meter readings and the automated monitoring results for water levels in the tank and rainfall depth. Daily totals of rainfall collected on the roof and directed to the tank, overflows from the tank, water use from the tank and maximum water levels in the rainwater tank are shown in Figure 3.

In Figure 3 it is shown that the volumes of overflows from the tanks are significantly less than the volumes of roof runoff directed to the tank. This indicates that the rainwater tank has significantly reduced the volumes of stormwater runoff discharging from the roof to the street drainage system. The range of the water levels shown in Figure 3 also indicates that the rainwater tank was able to reliably meet water demand during the monitoring period.

The automated monitoring data from the period 5/03/2001 to 21/08/2001 was combined with the meter readings for the period 1/11/2000 to 1/11/2001 to determine the impact of the rainwater tank. This period represented a continuous record without missing data. A total of 27,800 litres of rainwater was used from the tank, 1,160 litres of mains water was required to top up the tank and 24,300 litres of mains water was used in the house. A 52% reduction in mains water use was experienced.

The total volume of roof runoff discharging to the rainwater tank was 70,500 Litres and 42,700 Litres of stormwater overflowed from the tank to the street drainage system. Stormwater runoff to the street from the roof area was reduced by 39%.

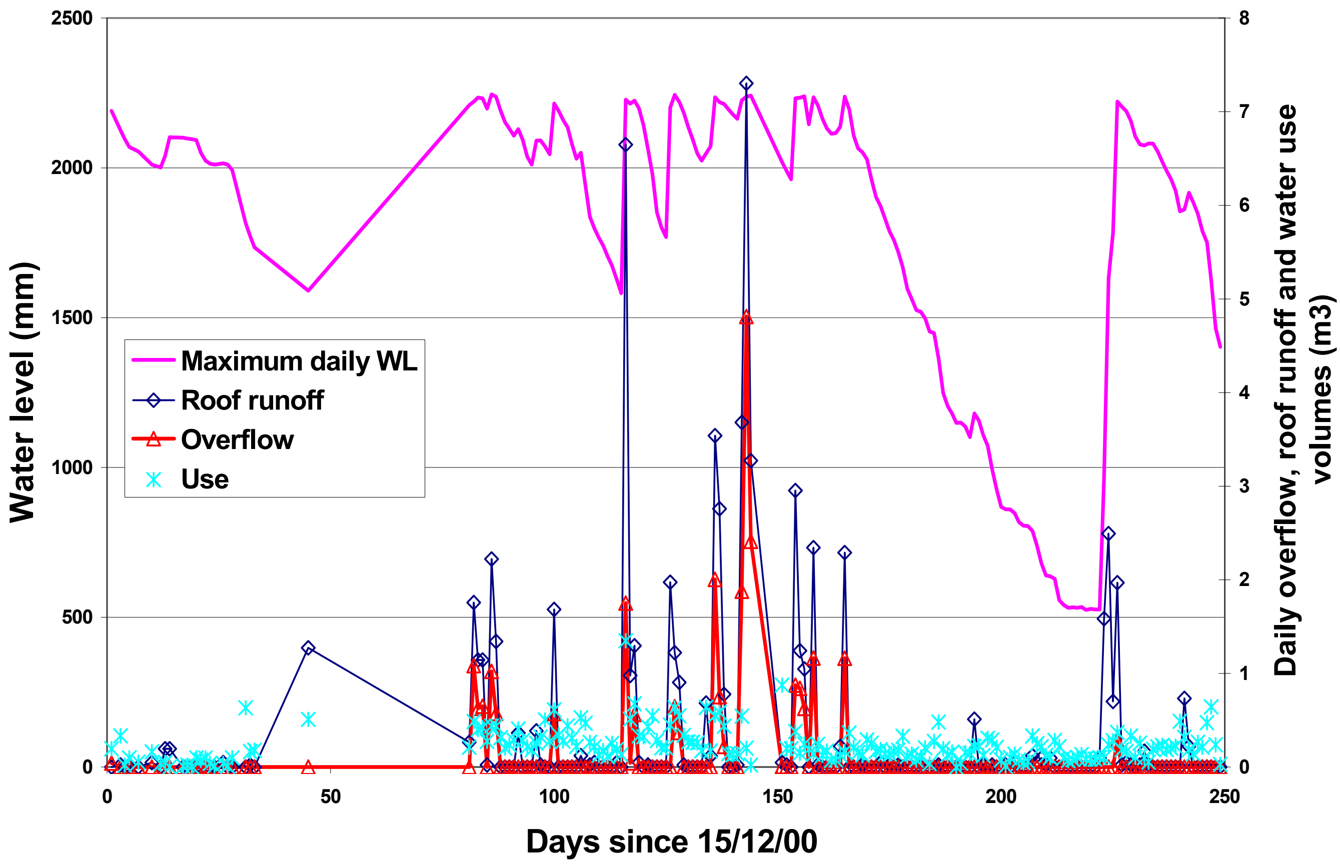

Figure 3: A daily time series of rainwater tank performance

The peak stormwater discharge from the rainwater tank was recorded as 0.0042 m^3/s and the peak stormwater discharge from the roof to the rainwater tank was 0.024 m^3/s. The use of the rainwater tank reduced the peak stormwater discharge from the roof by 86%.

The peak (maximum) daily water use from the tank was measured as 1,349 Litres. The peak daily mains water use was unknown although the average daily mains water use was observed to be 138 Litres. Large variations in mains water use were not expected because there was very little outdoor water use due to the small garden area. Therefore the peak factor of 2.4 suggested by Maheepala et al. [2001] was used to estimate the peak daily mains water demand of 334 Litres. The total peak demand is therefore estimated to be 1,683 Litres/day. Therefore use of the rainwater tank appears to have reduced peak daily mains water use by approximately 80% (1,349 Litres).

The maximum instantaneous peak demand (flow rate in the water distribution pipes) from the rainwater tank was recorded as 0.16 Litres/second. Using an instantaneous peak factor of 2.5 (Shipton, 1999) and the daily maximum mains water demand previously defined (334 Litres) the mains instantaneous demand is estimated to be 0.01 Litres/second. The total peak instantaneous demand was calculated to be 0.17 Litres/second. The use of the rainwater tank with mains water trickle top up to supply hot water and toilet flushing at the Maryville house has resulted in a 94% (0.16 Litres/second) reduction in the instantaneous peak demand for mains water.

The maximum water level in the rainwater tank was found to be 2.246 m. This water level is considerably lower than the level of the invert of the mains top up pipe (2.4 m) indicating that there was no risk of cross connection between mains water and rainwater during the monitoring period. Even if the water level reached 2.4 m during a storm the joint probability of a major storm and negative mains pressure occurring together is virtually zero. Backflow of rainwater into the mains water system is highly improbable.

Mains water use at the Maryville house for HWC billing periods is compared to the mains water use from the same billing periods in the previous year in Figure 4. Period 3a refers to the July to November period in the year 2000, period 1 is the November to March period in the year 2000/2001, period 2 is the March to July period in the year 2001 and period 3 is the July to November period in the year 2001.

In period 3a (Figure 4) the current and previous water demand was very similar because the rainwater supply system was not yet in use. The use of the rainwater tank during periods 1, 2 and 3 created substantial reductions in mains water use in comparison to the previous year. The annual mains water demand was 208,000 Litres in the previous year and 62,200 Litres in the current year. The use of the rainwater tank has resulted in a 70% mains water saving (145,800 Litres) in comparison to the previous year.

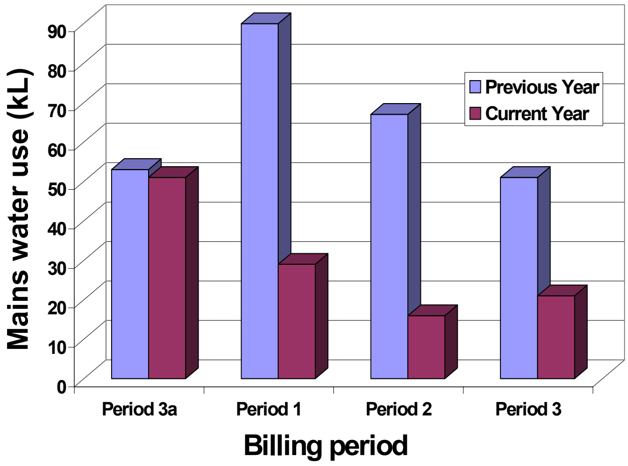

Figure 4: Mains water use at the Maryville house

The daily average rainfall depth was 3.3 mm/day in 1999, 3.12 mm/day in 2000 and 3.14 mm/day during the monitoring program. Similar rainfall depths were experienced during the period of study and the previous year. Thus the climatic influence on water use may be minimal. Given that the garden area is small this is likely. Moreover the daily average rain depth during the monitoring period is similar to the long-term daily average rainfall depth of 3.12 mm/day. Therefore the water savings reported here are likely to be consistent with potential long-term savings. Indeed Coombes (2002) analysed the long-term performance of the Maryville house using continuous simulation of the household water balance and found that the use of the rainwater tank will reduce mains water use by 63%.

The observed total water use at the house for the period 5/03/2001 to 21/08/2001 was 53,300 Litres. This can be extrapolated to determine an annual total water use of 120,000 Litres. The total annual water use during the period with the rainwater tank (120,000 Litres) was considerable less than the annual water use in the period without the rainwater tank (208,000 Litres). This difference can be attributed to demand moderation created by the presence of the rainwater tank and variations in the numbers of occupants in the house.

Interviews with the tenants revealed that the presence of the rainwater tank motivated an intense interest in water conservation and that rainwater from the tank was rarely used for outdoor uses due to the low pressure available at the tap in the rainwater tank. Greater utilisation of rainwater for outdoor uses would have eventuated if water for outdoor uses were also provided via the pump. Outdoor water use at the Maryville house was minimal because the garden area was very small.

Water Quality

Water samples were taken to determine water quality from the tap in the rainwater tank and from the hot water tap at the kitchen sink in the house. The tap in the rainwater tank is situated 0.6 m above the base of the tank. Samples collected from the rainwater tank and hot water system were tested for the parameters shown in Table 1 that also shows the guideline values from the Australian Drinking Water Guidelines (NHMRC, 1996).

Bacterial enumerations were conducted by the membrane filtration technique using Teepol broth for Fecal Coliforms, McConkey agar for Total Coliforms, Tryptone glucose extract for Heterotrophic Plate Counts and Pseudomonas selective broth for *Pseudomonas Spp.* The water quality analyses were carried out in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 1995). The water quality results from 12 samples taken from the rainwater tank are shown in Table 1. The majority of parameters tested (Table 1) complied with the Australian Drinking Water Guidelines although the average values for Total Coliforms, pH and Zinc in the water from the rainwater tank exceeded the recommended drinking water guideline.

The guideline values for Fecal Coliforms (10 CFU/ 100 ml) and Ammonia were exceeded on one occasion immediately following a rain event. These exceedances also corresponded to maximum values for Total Coliforms (161 CFU/100 mls), Heterotrophic Plate Count (4500 CFU/ml) and *Pseudomonas Spp*. (13200 CFU/100 mls). Gardner et al., (2001) also detected microbial activity in a rainwater tank immediately following rainfall events. The presence of Fecal Coliforms indicate the possibility of fecal contamination of the water and elevated levels of Ammonia can also indicate that the water contains organic compounds, human or animal excrement. However other organisms, such as *Aeromonas spp*., can also present as presumptive Coliform organisms (NHMRC, 1996) It is important to note that only presumptive tests for Coliforms were carried out. The increased levels of microbial contamination may have resulted from the only period of construction activity on the house roof during the monitoring that was prior to the storm event. The source of increased microbial contamination during that rain event may have been organic material from work boots deposited on the roof surface immediately prior to the rain event.

The average concentration of Zinc in the tank water was observed to be 3.9 mg/L and the maximum value was 5.3 mg/L. The rusty galvanised iron roof may cause these elevated concentrations. NHMRC (1996) report that there is no health based guideline for zinc although concentrations exceeding 3 mg/L may cause taste problems in water.

The average value of pH in the tank water (5.7) was observed to be marginally below the lower guideline value of 6.5 although the lowest value was 4.9. There is no health-based guideline for pH and NHMRC (1996) reports that the consumption of food or beverages with low (2.5) or high pH (11) does not result in adverse health effects. Contact with water with pH values below 4 can cause eye irritation and pH values above 10 can cause skin irritation (NHMRC, 1996). Water with pH values greater than 11 and less than 6.5 can, under some conditions, may corrode plumbing fittings or pipes.

The water quality in the rainwater tank (Table 1) is significantly better than the quality of roof runoff from the nearby Figtree Place development (Coombes et al., 2000). Similar to the Figtree Place development the Maryville house is close to industry and high traffic roads therefore similar water quality is expected from both roofs. The quality of roof runoff is improved in the rainwater tank. The exceedance of the drinking water guidelines for Fecal and Total Coliforms and Ammonia indicate the possible contamination of the rainwater supply and the elevated levels of Zinc may diminish the taste of the water.

The rainwater supply is not used for drinking therefore the quality may be acceptable provided the hot water meets the drinking water guidelines because the hot water may find potable uses. Hot water quality is shown in Table 2.

The water quality results from 5 samples (Table 2) show that the hot water quality complied with the Australian drinking water guidelines except for pH and Zinc. The Fecal Coliforms, Total Coliforms and Pseumonas Spp. were eliminated from the water and the average value of the Heterotrophic Plate Count was reduced to 4 CFU/ml.

Table 1: Water quality in the rainwater tank at the Maryville house

Parameter	Unit	Average	Maximum	Minimum	Guideline
Fecal Coliforms	CFU/100 ml	0.83	10	0	0
Total Coliforms	CFU/100 ml	18	161	0	0
Heterotrophic Plate Count	CFU/ml	784	4500	30	NA
Pseudomonas Spp.	CFU/100 ml	1673	13200	0	NA
Sodium	mg/L	7.50	16.50	3.20	180
Calcium	mg/L	2.50	6.50	0.70	200
pH		5.70	6.10	4.90	6.5 - 8.5
Dissolved solids	mg/L	67.30	168	4	500
Suspended solids	mg/L	19.10	178.00	0.40	500
Chloride	mg/L	9.90	17.60	5.70	250
Nitrate	mg/L	<0.05	<0.05	<0.05	3
Nitrite	mg/L	1.40	3	0.20	50
Sulphate	mg/L	5.90	11.10	0.40	250
Ammonia	mg/L	0.30	0.60	0.10	0.5
Lead	mg/L	<0.01	<0.01	<0.01	0.01
Iron	mg/L	<0.06	<0.06	<0.06	0.3
Zinc	mg/L	3.90	5.30	0.40	3
Cadmium	mg/L	<0.002	<0.002	<0.002	0.002

Table 2: Hot water quality at the Maryville house

Parameter	Unit	Average	Maximum	Minimum	Guideline
Fecal Coliforms	CFU/100 ml	0	0	0	0
Total Coliforms	CFU/100 ml	0	0	0	0
Heterotrophic Plate Count	CFU/ml	4	10	1	NA
Pseudomonas Spp.	CFU/100 ml	0	0	0	NA
Sodium	mg/L	8.40	1.70	5.20	180
Calcium	mg/L	2.00	4.20	0.80	200
pH		5.50	6.10	5.10	6.5 - 8.5
Dissolved solids	mg/L	15.80	26	4	500
Suspended solids	mg/L	0.50	0.60	0.30	500
Chloride	mg/L	9.90	11.00	7.40	250
Nitrate	mg/L	<0.05	<0.05	<0.05	3
Nitrite	mg/L	1.00	2.1	0.20	50
Sulphate	mg/L	5.20	10.10	2.60	250
Ammonia	mg/L	0.20	0.40	0.10	0.5
Lead	mg/L	<0.01	<0.01	<0.01	0.01
Iron	mg/L	<0.06	<0.06	<0.06	0.3
Zinc	mg/L	3.90	5.00	0.40	3
Cadmium	mg/L	<0.002	<0.002	<0.002	0.002

The average and maximum values of the Heterotrophic Plate Counts are considerably less than the Japanese and American health guideline value of 100 CFU/ml (Fujiwara et al., 1992).

The results for hot water quality are similar to the findings for hot water quality at Figtree Place (Coombes et al., 2000) although the hot water service at Maryville is different to the hot water services at Figtree place. Figtree Place has storage hot water services and the Maryville house has an instantaneous hot water service. It was hypothesised that bacteria are eliminated from the storage hot water systems at Figtree Place as a result of the processes of pasteurisation and tyndallization. Clearly this may not be the case at the Maryville house due to the instantaneous nature of the hot water service. It is assumed that bacteria is eliminated by pressure in the pump and by the instantaneous heat differential between the rainwater tank and the hot water service. Prescott et al., (1999) report that heat kills bacteria more readily at low population numbers, in acid conditions and rapid changes of temperature. Excluding the possibility of unacceptable taste and corrosion of plumbing the rainwater supply at the Maryville house was acceptable for outdoor, toilet and hot water uses.

Given that people are unlikely to drink from the hot water tap (Coombes, 2002) the possibility of unacceptable taste may not be an issue.

Costs

There is considerable debate about the cost of rainwater supply to a house. It is commonly believed that it would cost over $4000 to install a small rainwater tank to a house and the rainwater supply will cost $1 - $14 per kL (A. Speers, CSIRO, personal communication, 2001; Van der Wal, 2000; ACTEW, 1994). The cost and performance of the rainwater supply system at Maryville were monitored closely in an attempt to understand the true costs and benefits of the system. The total cost to install the rainwater supply system was $1851 and the itemised costs are shown in Table 3.

Installation of the above ground rainwater tank system at the Maryville house cost considerably less than $4,000. One of the common assumptions held about rainwater tanks is that they occupy a large area and therefore they must be installed underground at considerably increased cost. However the large 9,060 Litre capacity rainwater tank at the Maryville house only occupies an area of 4 m^2 and a 5,000 Litre rainwater tank will occupy a 2 m^2 area.

Table 3: Costs to install the rainwater supply system in 1999 (Australian $)

Item	**Cost ($)**
Aquaplate tank	864
Pump + pressure control	200 + 144
Plumber	300
Fittings	50
Float system	60
Concrete slab	150
Electrician	83
Total	**1851**

The method of present equivalence by Smith (1979) can be used to calculate the present value of the rainwater supply solution and the cost per kL of the rainwater supply. The following assumptions are made:

- The real interest rate is 5%,
- the tank has a 25 year structural warrantee therefore it has a 50 year life. The replacement cost is $864,
- the pump has a 10 year life therefore the replacement cost is $200,
- the pump uses 0.29 kW of energy per kL of rainwater used thus the energy costs were $0.028 per kL and no maintenance was required (Coombes, 2002); the operating and maintenance costs of the system are assumed to be $0.05 per kL of rainwater used, and
- the price of mains water is $0.94 per kL and wastewater discharge is charged on the basis of mains water use at $0.20 per kL

The rainwater supply system (RSS) at the Maryville house is estimated to save 62 kL of mains water each year. Three scenarios are evaluated to estimate the present value of the rainwater supply system and the cost of rainwater, including:

- the Maryville rainwater supply system,
- the Maryville rainwater supply with a $35 per year rate rebate from local government for the stormwater management impact of the rainwater tank, and
- the Maryville rainwater supply system with a $35 per year rate rebate from local government, a $960 saving in new stormwater infrastructure costs [Coombes et al., 2000) and a saving of $500 on new water supply infrastructure costs (Shipton, 1999).

The present value and cost of rainwater for each scenario is shown in Table 4.

Table 4: Economic analysis of the rainwater supply system at the Maryville house

Scenario	Present value ($)	Cost of rainwater ($/kL)
RSS	-918	0.30 (cost)
RSS + $35 per year rebate	-248	0.08 (cost)
RSS + infrastructure savings + $35 per year rebate	1212	0.39 (benefit)

The cost of rainwater at the Maryville house is estimated to be $0.30/kL (Table 4), which is significantly less expensive than the price of mains water and is considerably less expensive than the commonly assumed cost of rainwater of $1 - $14 per kL. The present cost of $918 may be a disincentive for the resident to install a rainwater tank.

Provision of an incentive (a rate rebate) of $35 per year by local government to encourage the installation of rainwater tanks to reduce downstream stormwater impacts will make the cost of rainwater $0.08/kL. With the inclusion of a stormwater infrastructure saving of $960 as determined from the Figtree Place development (Coombes et al., 2000) and water supply infrastructure saving of $500 (Shipton, 1999) the benefit of the rainwater supply system will be $0.39/kL.

Conclusions

Monitoring of the performance (during a 169 day period) of the dual water supply system at the Maryville house revealed that use of the rainwater tank reduced stormwater volumetric (36%) and peak discharges (86%), and mains water peak daily (80%), peak instantaneous (94%) and volumetric (52%) demands. The widespread installation of rainwater tanks is likely to significantly reduce the requirement for new dams, water supply and stormwater drainage infrastructure.

The dual water supply system was installed at a cost of $1851, which is considerably less than the commonly assumed cost of over $4,000. The cost of rainwater varied from $0.30/kL to a benefit of $0.39/kL when a rates rebate and savings in the construction of water cycle infrastructure was considered.

The cost of water supply from a rainwater tank appears to be significantly less than the price of mains water in the Lower Hunter region therefore rainwater supply can be competitive with the mains water supply or an affordable complement to the mains water supply. Importantly when savings to water supply and stormwater infrastructure and a small rate rebate are included in the analysis the rainwater supply system produced considerable benefit to the resident. It should be noted that the value of infrastructure savings are approximate and the benefits of delaying the need to build new water supply dams and reduced impact on the environment have not been included in the analysis. A complete analysis of the entire urban water cycle with the introduction of rainwater tanks may reveal considerable benefits to the community.

Monitoring of water quality from the rainwater tank and from an instantaneous hot water service at the Maryville house revealed that the rainwater was acceptable for hot water, toilet and outdoor uses. Similar to the water quality results from the Figtree Place experiment (Coombes et al., 2000) water quality was found to improve in the rainwater tank and the hot water service.

Acknowledgements

The authors gratefully acknowledge the funding support provided by Newcastle City Council and the NSW Government Stormwater Trust.
Associate Professor Hugh Dunstan from the School of Biological and Chemical Sciences and Chris Dever from the School of Geosciences at the University of Newcastle provided valuable assistance in the analysis of the project.

Assistance in the development of the Maryville project was also provided by Bruce Peterson from Hunter Water Corporation and Neil Roser from Newcastle City Council.

The content of this paper was also enhanced by the anonymous contribution from the conference reviewer.

References

APHA (1995). Standard methods for examination of water and wastewater. 19th ed., American Public Health Association. New York, USA.

ACTEW (1994). ACT future water supply strategy. Our water our future. ACT Electricity and Water.

Coombes, P.J., Argue, J.R. and Kuczera, G., (2000). Figtree Place: A case study in water sensitive urban development, Urban Water, 1(4). 335-343.

Coombes P.J., (2002). Rainwater tanks revisited: new opportunities for urban water cycle management. Unpublished PhD. thesis. University of Newcastle, Callaghan, NSW.

Fujiwara M., Manwaring J.M., and Clarke R.M., (1992). Drinking water in Japan and the United States: Conference Objectives. The proceedings of the 3rd U.S. – Japan Governmental Conference on Drinking Water Quality Management. Cincinnati, Ohio, USA.

Gardner T., Coombes P.J., and Marks R., (2001). Use of rainwater at different scales in Australian environments. 10th International rainwater Conference. Germany.

Maheepala S., Shipton R.J., Rahilly M., and Marquez L., (2001). Water Odyssey – 2001. AWA 19th Convention. Canberra, Australia.

NHMRC (1996). Australian Drinking Water Guidelines. National Health and Medical Research Council. Commonwealth of Australia, Sydney Australia.

Prescott L.M., Harley J.P., and Klein D.A., (1999). Microbiology. McGraw-Hill. Sydney, Australia.

Shipton R.J., (1999). Peak levelling in urban water reticulation systems. Research report. CSIRO Urban Water. Melbourne, Australia.

Van der Wal B., (2000). Increasing the viability of urban runoff and sewage effluent as supplementary sources of water in country towns of South Australia. Australian Journal of Water Resources. 4(2). 89-97.

Author Biographies

Peter Coombes MIE B.E. (Civil) (Hons), B. Survey (Hons). Dip. Eng. (Hons) recently completed a PhD on the topic "Rainwater tanks revisited: new opportunities for urban water cycle management" at the University of Newcastle. He has 20 years experience in the water resources industry and is the NSW Chairman of the Stormwater Industry Association. He has recently been appointed as a Post Doctoral Fellow on a research program to develop strategies for optimal source control in urban water cycle management.

Postal address: Peter Coombes, Civil, Surveying and Environmental Engineering, School of Engineering, University of Newcastle. Callaghan. NSW 2308.

E-mail: pcoombes@mail.newcastle.edu.au
Web: www.eng.newcastle.edu.au/~cegak/Coombes

George Kuczera is an associate professor in Civil Engineering at the University of Newcastle. His research interests include stochastic modelling of rainfall at different time scales, parameter estimation, model testing and prediction, urban hydrology, and water resource system simulation and optimisation.

Postal Address: Civil, Surveying and Environmental Engineering, School of Engineering, University of Newcastle, Callaghan, NSW, 2308

E-mail: cegak@cc.newcastle.edu.au

Jetse Kalma is the Hunter Water Corporation professor of Environmental Engineering at the University of Newcastle. His research interests include catchment hydrology, environmental physics and the impact on urban water use on surface and ground water systems.

Postal Address: Civil, Surveying and Environmental Engineering, School of Engineering, University of Newcastle, Callaghan, NSW, 2308

E-mail: cejk@alinga.newcastle.edu.au