Chapter 3

The Maryville House Experiment

> "Water is the precious life substance of the earth. Its value to the environment, climate and life of our world will be increasingly recognised. Violated, humiliated, piped, contaminated, less and less can it unfold its selfless qualities and perform its life-supporting task. Awareness, care and perceptive consciousness are being asked of humanity." Wolfgang Geiger and Herbert Dreiseitl [1995].

3.0 Introduction

Although the performance of the dual water supply (rainwater and mains water) scheme at Figtree Place (Chapter 2) was obfuscated by intermittent operation of the system due construction errors, ongoing reconstruction and a defective solenoid valve configuration it was apparent that rainwater tanks can be designed to provide significant reductions in mains water use and stormwater discharges. The Maryville House experiment was initiated to implement the lessons learnt from the Figtree Place experiment and to further develop an understanding of the performance of a dual water supply system. What reductions in mains water demand and stormwater discharges can realistically be expected from a house with rainwater used to supply hot water, toilet and outdoor uses?

An old house in Maryville, an inner city suburb of Newcastle in New South Wales, Australia was fitted with an above ground 9,060 L 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 has on average of three occupants. 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. Will the water quality from the "real" rainwater tank and from the hot water service be acceptable given that the site has a rusty galvanised iron roof and does not have a first flush separation device?

This chapter discusses the design, construction, costs and performance of the dual water supply system. Water quantity and quality results from the monitoring program are also presented. The results of the Figtree Place and Maryville experiments will be combined with an exploration of public health issues resulting from use of rainwater tanks in Chapter 4 and institutional resistance to the use of rainwater tanks in Chapter 5 to provide a foundation for an analysis of the impact of the use of rainwater tanks on the urban water cycle.

3.1 Design of the Dual Water Supply Solution

A dual water supply solution using rainwater from a tank to supplement mains water supply for toilet flushing, hot water and outdoor uses was proposed for the Maryville house. The design conditions imposed by Australian standards, the NSW Department of Health, water authorities and local government for dual water supply using rainwater tanks and mains water are examined in this section. The design method chosen for the Maryville house is also presented.

3.1.1 The NSW Department of Health Guidelines

The NSW Department of Health does not prohibit the use of rainwater for drinking or other purposes [Corbett, 2001]. The Department recommends proper use and maintenance of rainwater tanks and provides a monograph "Guidance on the Use of Rainwater Tanks" [Cunliffe, 1998] to assist with this task. The focus of NSW Department of Health guidelines is drinking water quality.

3.1.2 Water Authority Recommendations

Water authorities cannot prohibit the reuse of rainwater or stormwater on private land [HWC, 1997 and Corbett, 2001]. Their primary concern is to maintain the quality of mains water. Accordingly, water authorities require the installation of an appropriate backflow prevention device or method to prevent contamination of mains water by rainwater [ASNZ3500.1.2, 1998]. There are many methods to establish a dual water supply scheme. The three methods considered were:

- Top up the rainwater tank with mains water from a garden hose when the tank empties [Mobbs, 1998];

- Trickle top up the rainwater tank with mains water to a minimum level when the rainwater tank water level falls below the minimum level. A mechanical float system is used to control the trickle top up and an air gap is used for backflow prevention [AS/NZ 3500.1.2, 1998] (This is the solution developed in Section 2.7.3);
- Switch between mains and tank water supply using a solenoid valve and a water level sensor in the rainwater tank. When the rainwater tank is empty mains water is used to supply all uses (This is the Figtree Place solution discussed in Chapter 2). A reduced pressure zone device (RPZD) is used for backflow prevention in this configuration.

The HWC recommended the use of a mains water top up system for the rainwater tank with the provision of an air gap between the rainwater and mains water supplies to prevent cross connection between the supplies [B. Petersen, personal communication, 1999]. Given the unreliable performance of the solenoid valve arrangement at Figtree Place (Chapter 2) and the relative simplicity of the air gap solution this method was adopted for the dual water supply at the Maryville house.

3.1.3 Local Government Policies

Local Councils have varying policies on the reuse of rainwater with some Councils not having any policy. Rainwater tanks are typically structures that may require development consent. However many councils have declared rainwater tanks to be ‘exempt development’ (which does not require consent) provided that certain requirements relating to structure size, height and siting are satisfied. If a development application is required to install rainwater or stormwater storage, details should be provided as to:

- The location of the storage and relationship to nearby buildings,
- The configuration of inlet/outlet pipes and overflow pipe,
- Storage capacity, dimensions, structural details and proposed materials, and
- The purposes for which the stored water is intended to be used.

Local Councils cannot prohibit the reuse of rainwater [Corbett, 2001]. However, where a Council is a water supply authority, it can require the installation of an appropriate backflow prevention device [AS/NZ 3500.1.2, 1998].

The proposed capacity of the Maryville rainwater tank (9,060 L) was greater than the maximum capacity permitted for exempt development by NCC (5,000 L). Hence a development application was submitted to NCC for the installation of the rainwater tank.

3.1.4 Australian Standards

Two Australian Standards, namely the Australian Drinking Water Guidelines [NHMRC, 1996] and AS/NZS 3500.1.2 National Plumbing and Drainage: Water supply - acceptable solutions, provide guidance for the use of rainwater tanks. The Australian Drinking Water Guidelines provide little assistance on reuse of rainwater for secondary quality purposes (such as outdoor, toilet, laundry and hot water uses) because their focus is on drinking water quality. Chapter 7 of the Australian Drinking Water Guidelines advises on the management of small potable water supplies, and Cunliffe [1998] provides advice on the management of rainwater tanks.

AS/NZ 3500.1.2 [1998] provides useful guidance for the design of rainwater reuse systems. Cross connection between mains water supply and premises with a rainwater tank is described as a low hazard requiring a non-testable backflow prevention device indicating that rainwater can be considered to be potable. The Standard provides guidance for the design of rainwater tanks with dual water supply (rainwater and mains water) [AS/NZ 3500.1.2, 1998, Section 8.5]. Rainwater tanks with dual water supply can maintain an air gap, and may be designed and connected as shown in Figure 3.1.

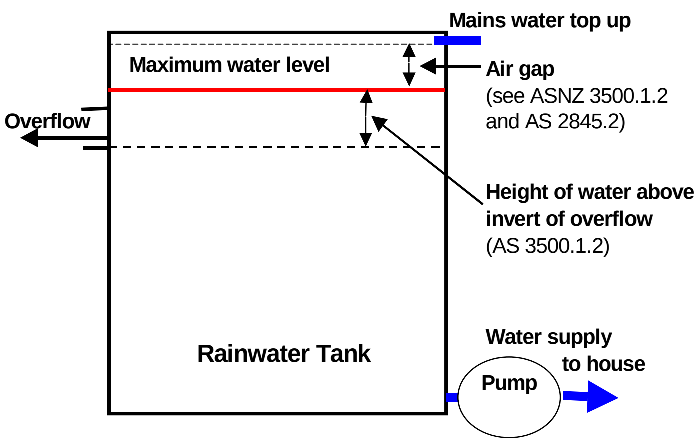


Figure 3.1: Design details to prevent backflow for a rainwater tank with mains water top up

The Standard explains (Figure 3.1) that the rainwater tank can be topped up with mains water provided that a separation (air gap) is provided between the mains water inlet and the expected maximum water level in the tank. The expected maximum water level and the air gap are defined as a function of the outlet and inlet diameters in the Standard.

3.1.5 Design of the Maryville Dual Water Supply Solution

The dual water supply system and the locations of monitoring devices at the Maryville house are shown in Figure 3.2. In the design the rainfall from a portion of the roof with an area of 115 m^2 was 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 was directly connected to the hot water service and the toilet cistern. Rainwater for outdoor uses was drawn directly from the rainwater tank. Mains water was supplied to the remainder of the house and is used to top up the rainwater tank when water levels are low (Figure 3.3).

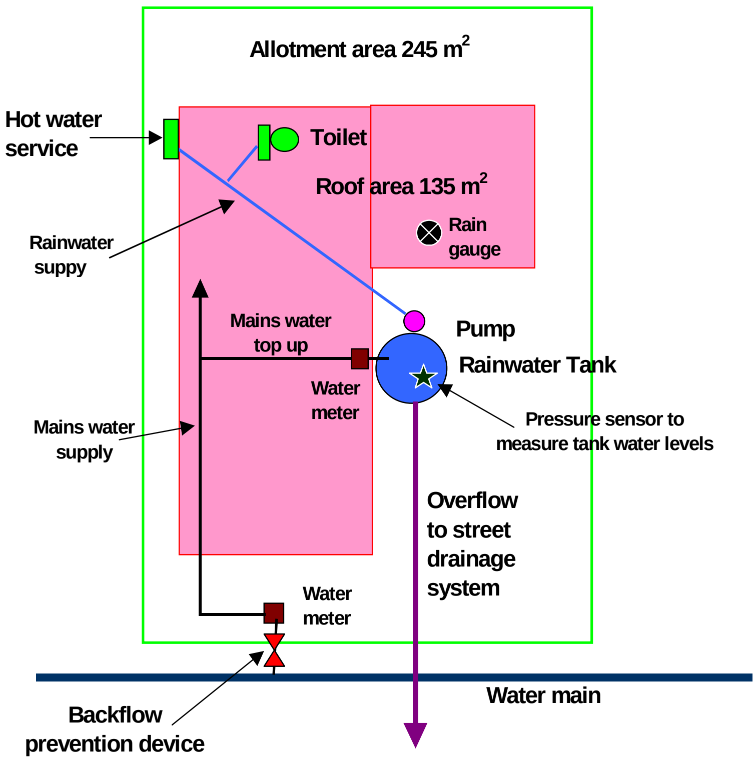
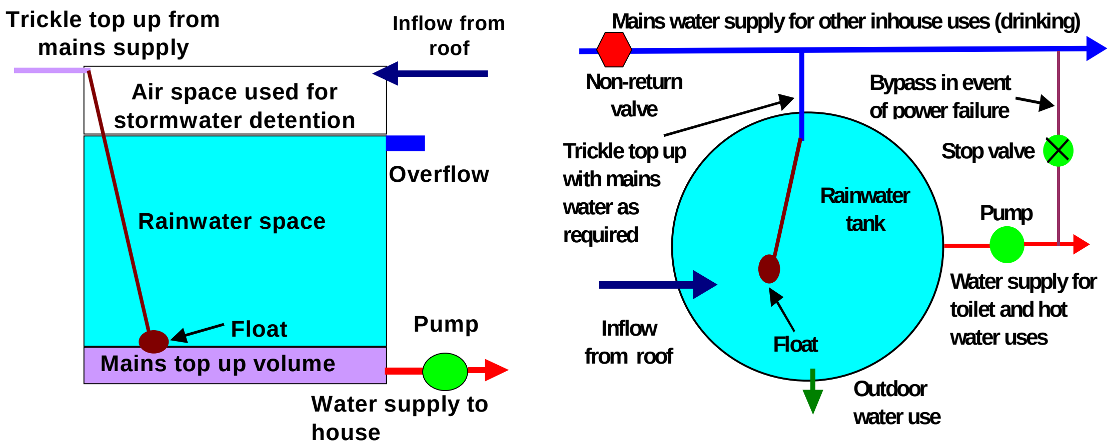


Figure 3.2: Diagram of the Maryville house with the dual water supply solution

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 was located on the house roof and a pressure sensor was used to record water levels in the rainwater tank. The observations from these devices were combined with readings from the meter on the mains water supply to the house to determine water use. The design of the rainwater tank with mains water top up system is shown in Figure 3.3.



Elevation view

Plan view

Figure 3.3: Rainwater tank with mains water top up system

The configuration of the dual water supply is shown in Figure 3.3. 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 (Figure 3.3) made 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 and backflow prevention.

The minimum storage volume should be set at the maximum daily water use that is expected from the tank. However the minimum storage volume for the Maryville rainwater tank was arbitrarily set at 1,185 L (a depth of 0.5 m). If the volume of stored water falls below the minimum storage volume, the shortfall is overcome by topping up the tank with mains water to the required level. A simple float valve system was installed to do this automatically. The operation of the float valve system provides trickle top up of the rainwater tank at a rate dependant on the water level in the tank. In the event of heavy outdoor water use the tank may be emptied if the trickle top up rate did not match the rate at which the pump can supply. The rainwater tank is topped up at mains water flow rate when the tank is empty and at a significantly reduced rate when the tank water level is only slightly below the minimum level. The float valve system operates to close or partially close the mains water top up pipe in response to water levels. The actual top up rates provided by the system are unknown. Further testing of the mains top up system is required to quantify the top up rates the system provides.

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 L (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 was fairly simple. 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 floats system. An electrician was used to install a power point close to the pump.

3.2 The Approval Process

A development that installs a rainwater tank with a capacity less than 5,000 L does not required a development application in accordance with NCC's exempt development provisions. It was intended to install a rainwater tank with a capacity of 9,060 L at the Maryville house. Therefore a development application was required.

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

Even though the dual water supply solution was approved by the HWC [B. Peterson, personal communication, 1999] there was concern at NCC about the reuse of rainwater for any purpose [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.

3.3 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. A manual monitoring program to collect and analyse water samples, and to measure mains water use commenced in August 1999. The automated monitoring program to measure rainfall and water levels in the tank commenced on the 16/12/2000. This section reports the water quality and quantity results.

3.3.1 Water Quantity

The monitoring results for mains water and rainwater use at the Maryville house are presented in this Section. The impact of the use of the rainwater tank on mains water use, and stormwater discharges is also discussed. The quantity of rainwater and mains water used can be 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 presented in Appendix F and summarised in Figure 3.4.

In Figure 3.4 it is shown that the volumes of overflows from the tank 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 3.4 also show that the rainwater tank was able to reliably meet water demand during the monitoring period.

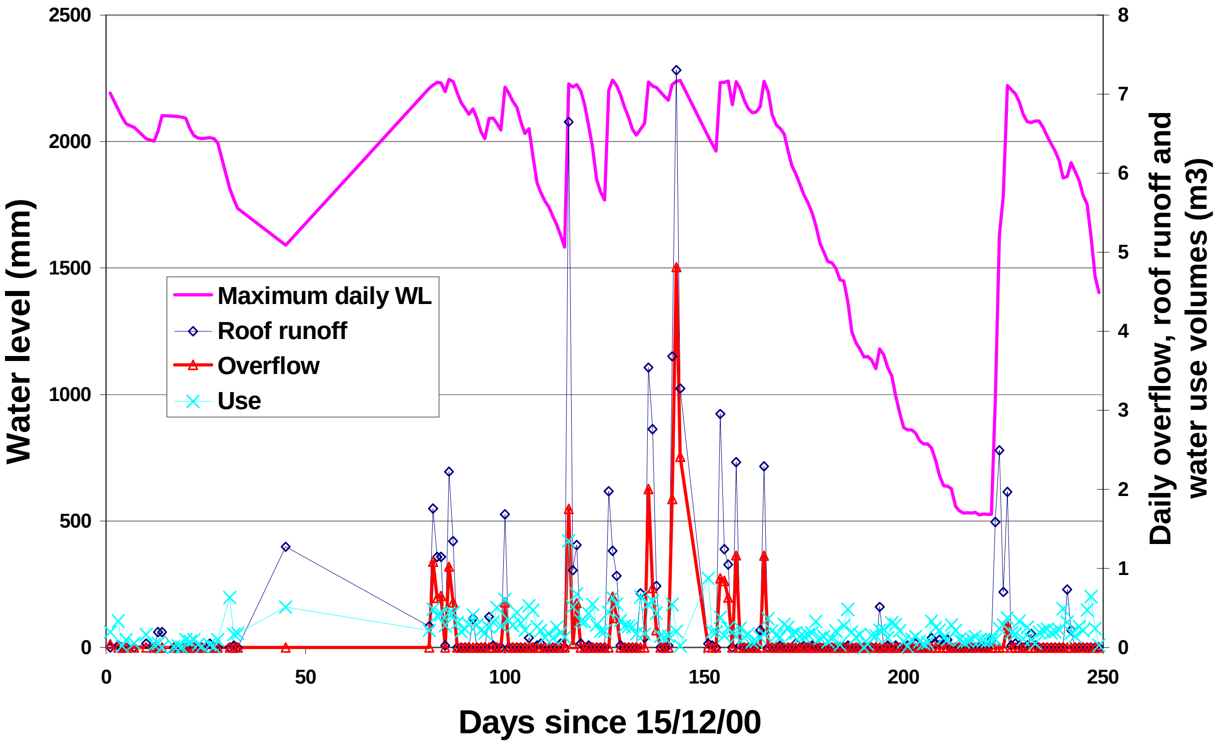


Figure 3.4: A daily time series of the rainwater tank performance

3.3.1.1 Reductions in Mains Water Consumption and Stormwater Discharges

The automated monitoring data for the period 5/03/2001 to 21/08/2001 was combined with the meter readings from the period August 1999 to November 2001 to determine the impact of the rainwater tank. Analysis was conducted for the period 5/03/2001 to 21/08/2001 because a continuous record without missing data was available for that period from the automated monitoring record. A total of 27,800 L of rainwater was used from the tank, 1,160 L of mains water was required to top up the tank and 24,300 L 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 L with 42,700 L of stormwater overflowing from the tank to the street drainage system. Stormwater runoff to the street from the roof area was reduced by 39%.

The results are consistent with the findings of many authors including Heeps [1977], Duncan and Wight [1991], Mitchell et al. [1997], Schilling and Mantoglou [1999] and Van der Wal [2000] who report that the use of rainwater tanks is expected to reduce mains water demand and stormwater discharges. The widespread adoption of rainwater tanks was expected to reduce the need for new stormwater infrastructure, delay the replacement of aging stormwater infrastructure and defer the requirement for new water sources [Heeps, 1977; Schilling and Mantoglou, 1999 and Van der Wal, 2000].

3.3.1.2 Reduction in Stormwater Peak Discharges

The maximum stormwater peak discharge from the rainwater tank was recorded at 0.0042 m^3/s and the maximum stormwater peak discharge from the roof to the rainwater tank was observed to be 0.024 m^3/s. The use of the rainwater tank reduced the stormwater peak discharge from the roof by 86% during the monitoring period. Reductions in stormwater peak discharges to the street drainage system will reduce the need for stormwater drainage infrastructure in the street.

3.3.1.3 Reduction in Peak Daily Water Demand

The peak (maximum) daily water use from the tank was measured as 1,349 L. The peak daily mains water use was unknown although the average daily mains water use was observed to be 138 L. 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 L. The total peak demand is therefore estimated to be 1,683 L/day. Therefore use of the rainwater tank appears to have reduced peak daily mains water use by approximately 80% (1,349 L).

Maheepala et al. [2001] found that the widespread adoption of storage tanks with trickle top up on urban allotments could reduce peak daily demand by 58% resulting in up to a 37% saving in the construction of new water distribution infrastructure. Alternatively reductions in peak daily demand were expected to significantly increase the service life of existing water distribution infrastructure. The estimate of daily maximum peak demand reductions from the Maryville house indicate that houses using rainwater tanks with mains water trickle top up systems can provide savings in the construction and operation of water distribution infrastructure.

3.3.1.4 Reduction in Peak Instantaneous Water Demand

The maximum instantaneous peak demand (flow rate in the water distribution pipes) from the rainwater tank was recorded as 0.16 L/s. Using an instantaneous peak factor of 2.5 [Shipton, 1999] and the daily maximum mains water demand previously estimated (334 L) the mains instantaneous demand is estimated to be 0.01 L/s. The total peak instantaneous demand was estimated to be 0.17 L/s. The use of the rainwater tank with mains water trickle top up to supply hot water and toilet flushing at the Maryville house has reduced the instantaneous peak demand for mains water by about 94% (0.16 L/second). Shipton [1999] reported that a 60% reduction of instantaneous demand would result in a 15% saving in the construction of water distribution infrastructure.

The peak daily demand reductions are expected to impact on the trunk water distribution system and peak instantaneous demand reductions are expected to impact on the smaller local distribution pipes that deliver water from the trunk system to the households [B. Berghout, HWC, personal communication, 2001]. It is often argued that the size of the local distribution system is dominated by fire fighting demand requirements; therefore installation of rainwater tanks cannot reduce its size. However, Heeps [1977], Shipton [1999] and Maheepala et al. [2001] suggest that trickle top up of storage tanks will allow the reductions in the size of local water distribution infrastructure by allowing more of the water pressure in the local distribution system to be available for fire fighting. The widespread introduction of rainwater tanks with mains water trickle top up may allow reduction in the size of new trunk and local water distribution infrastructure and reduce demands on existing infrastructure.

3.3.1.5 Risk of Cross Connection Between Mains Water and Rainwater in the Tank

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 top up system appears to be highly improbable.

3.3.1.6 Comparison to Main Water Use Prior to Installation of the Rainwater Tank

Mains water use at the Maryville house for HWC billing periods are compared to the mains water use for the same billing periods in the previous year in Figure 3.5. Period 3a refers to the July to November in 2000, period 1 is the November to March in 2000/2001, period 2 is the March to July in 2001 and period 3 is the July to November period in 2001.

In period 3a (Figure 3.5) 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 L in the previous year and 62,200 L in the current year. The use of the rainwater tank has resulted in a 70% mains water saving (145,800 L) in comparison to the previous year.

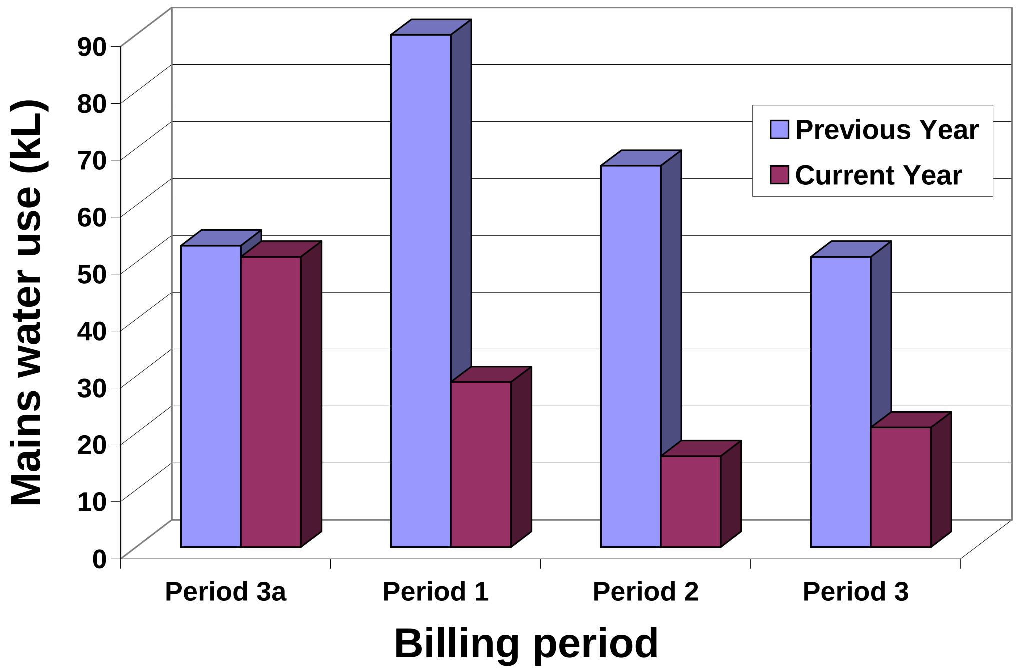


Figure 3.5: Mains water use comparison to previous years by HWC billing period

The observed total water use at the house for the period 5/03/2001 to 21/08/2001 was 52,300 L. This can be extrapolated to an annual total water use of 120,000 L. The total annual water use during the period with the rainwater tank (120,000 L) was considerably less than the annual water use in the period without the rainwater tank (208,000 L). This difference can be attributed to demand moderation created by the presence of the rainwater tank, different water usage in response to different climate patterns 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 in the household 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. The tenants also stated that they used very little mains water on the small garden area. Greater utilisation of rainwater for outdoor uses would have eventuated if water for outdoor uses was also provided via the pump.

Very little mains water was used for outdoor uses and the rainwater tank supplied mostly hot water and toilet uses. Thus water consumption for hot water and toilet is estimated to be 52% of total indoor water use. This result is similar to the percentages of total indoor consumption that was hot water and toilet use at the Figtree Place experiment (Table 2.11).

3.3.2 Water Quality

Rainwater collected from the house roof and stored in the Aquaplate rainwater tank was used to meet hot water and toilet flushing demand at the Maryville house. Rainwater quality from the tank and hot water system was monitored from October 2000 until August 2001. 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 for outdoor water use was 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 2.1. 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]. Monitoring results for water quality are discussed in this Section and are shown in Appendix F. The water quality results from 12 samples taken from the rainwater tank are shown in Table 3.1.

The majority of parameters tested (Table 3.1) 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 guidelines (shown as guideline in Table 3.1). The guideline values for Fecal Coliforms 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 ml), Heterotrophic Plate Count (4,500 CFU/ml) and Pseudomonas Spp. (13,200 CFU/100 ml). Gardner et al. [2001] also detected microbial activity in a rainwater tank immediately following rainfall events. It is noted that the rainwater tank system at the Maryville house does not include a first flush device. Installation of a first flush device to separate the first flush of roof runoff from entry to the rainwater tank may have significantly reduced the contaminant load transported to the rainwater tank during the rainfall event.

Table 3.1: Water quality in the rainwater tank at the Maryville house (based on 12 samples)

Parameter	Unit	Average	Maximum	Minimum	Guideline
Fecal Coliforms	CFU/100 ml	0	10	0	0
Total Coliforms	CFU/100 ml	18	161	0	0
Heterotrophic Plate Count	CFU/ml	784	4,500	30	NA
Pseudomonas Spp.	CFU/100 ml	1,673	13,200	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

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, 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 construction activity on the house roof prior to the storm event. The source of increased microbial contamination may have been organic material from work boots deposited on the roof surface.

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. Water with pH values greater than 11 and less than 6.5 can, under some conditions, corrode plumbing fittings or pipes.

A comparison between water quality in the rainwater tank at Maryville and the water quality at the point of supply in the rainwater tanks at Figtree Place is shown in Table 3.2.

Table 3.2: Rainwater quality in the Maryville tank and at the point of supply in the Figtree Place tanks

Parameter	Unit	Figtree roofwater averages	Maryville average	Figtree average	Difference (%)
Fecal Coliforms	CFU/100 ml	135	0	0	0
Total Coliforms	CFU/100 ml	359	18	127	-86
Heterotrophic Plate Count	CFU/ml	1,362	784	351	123
Pseudomonas Spp.	CFU/100 ml	59,604	1673	4433	-62
Sodium	mg/L	11.4	7.50	5.58	34
Calcium	mg/L	2.75	2.50	9.68	-74
pH		5.76	5.70	6.03	-10
Dissolved solids	mg/L	57	67.30	129	-48
Suspended solids	mg/L	35	19.10	1.37	1294
Chloride	mg/L	14.88	9.90	10.38	-5
Nitrate	mg/L	0.34	<0.05	<0.05	0
Nitrite	mg/L	2.16	1.40	0.90	56
Sulphate	mg/L	6.7	5.90	7.53	-22
Ammonia	mg/L	0.36	0.30	0.11	173
Lead	mg/L	0.014	<0.01	<0.01	0
Iron	mg/L	0.05	<0.06	0.10	-40
Zinc	mg/L	0.62	3.90	0.17	2194
Cadmium	mg/L	<0.002	<0.002	<0.002	0

Similar to the Figtree Place development the Maryville house is close to industry and high traffic roads therefore similar water quality was expected from both roofs. The quality of rainwater in the Maryville tank is shown in Table 3.2 to be better than the quality of rainwater measured at the point of supply in the Figtree Place tanks for most parameters. The improved rainwater quality from the tank at Maryville could be attributed to the better quality rainwater tank used at the Maryville house. The damaged tanks at Figtree Place allowed leaves and debris to enter the stored water from surrounding garden areas during storm events. If a first flush pit had been installed at the Maryville house even better results would have been expected.

Greater values for Heterotrophic Plate Counts, Suspended Solids, Sodium, Nitrite, Ammonia, pH and Zinc were found in the Maryville tank. The Maryville house is situated about 500 m from the ocean. This is closer to the ocean than Figtree Place and could have caused the higher concentrations of Sodium in the tank water. The elevated levels of zinc in the Maryville tank could be attributed to the rusty galvanised iron roof at the Maryville house.

The Maryville tank was installed above ground and the Figtree Place tanks are installed underground. Greater water temperatures in the Maryville tank may cause increased values of Heterotrophic Plate Counts, Nitrite and Ammonia. The Maryville house is closer to heavy industry than the Figtree Place development. This may result in higher values for Suspended Solids in the Maryville tank. The higher values of Suspended Solids in the Maryville tank could also be attributed to the absence of a first flush pit. The higher values of pH in Figtree Place tanks are due to the effect of the concrete tanks. The weak acidity of the rainwater is readily buffered by the alkali nature of the concrete storage tanks.

The samples from the point of supply at the Figtree Place tanks were taken downstream of the water supply pumps. The pressure generated inside the pump may have eliminated some of the Heterotrophs from the rainwater supply at Figtree Place. The effect of pumps on the viability of bacteria is unknown.

The exceedance of the drinking water guidelines for Fecal and Total Coliforms and Ammonia in the Maryville rainwater tank indicate possible fecal 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 water from the hot water service complies with drinking water guidelines because the hot water may find potable uses. Hot water quality is shown in Table 3.3.

The water quality results from 5 samples (Table 3.3) show that the hot water quality complied with the Australian drinking water guidelines except for pH and Zinc. The Fecal Coliforms, Total Coliforms and Pseudomonas Spp. were eliminated from the water and the average value of the Heterotrophic Plate Count was reduced to 4 CFU/ml. 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].

Table 3.3: Hot water quality at the Maryville house (based on 5 samples)

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 results for hot water quality are similar to the findings for hot water quality at Figtree Place (Section 2.5.4) 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. Perhaps bacteria are 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 during 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 most people do not drink from the hot water tap (Section 2.3) the possibility of unacceptable taste may not be an issue. Concentrations of Copper in hot water were not measured during this research program. The impact of the low pH of rainwater on copper pipes in household plumbing was not determined. Future research should measure the concentrations of Copper in rainwater tank systems to determine if rainwater increases corrosion in household plumbing. Installing non-metallic household plumbing may reduce the risk of corrosion.

3.4 Costs

There is considerable debate about the cost of rainwater supply to a house. It is commonly believed that it would cost over $4,000 to install a rainwater tank to a house and the rainwater supply will cost $1 - $14 per kL [Van der Wal, 2000; ACTEW, 1994; A. Speers, CSIRO, personal communication; 2001, C. Howe, Sydney Water Corporation, personal communication, 2001]. Gosford Wyong Council's Water Authority (GWCWA) argues that the installation of a small (4,000 L) rainwater tank will cost more than $2,300, provide little or no benefit and is thus too expensive [GWCWA, 2000]. The costs 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 with the itemised costs shown in Table 3.4.

Table 3.4: Costs to install rainwater supply system

Item	**Cost ($)**
Aquaplate tank	864
Pump + pressure controller	200 + 144
Plumber	300
Fittings	50
Float system	60
Concrete slab	150
Electrician	83
Total	**1,851**

Installation of the on ground rainwater tank system at the Maryville house cost considerably less than the commonly believed $4,000 and the assumed $2,300 for a small rainwater tank. One of the common assumptions held about rainwater tanks is that they occupy a large area therefore they must be installed underground at considerably increased cost. However the large 9,060 L capacity rainwater tank at the Maryville house only occupies an area of 4 m^2 and a 5,000 L rainwater tank will occupy an area of 2 m^2.

The method of present equivalence [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 and therefore is assumed to have 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 electricity per kL of rainwater use (Appendix F). The energy costs are $0.028 per kL and no maintenance was required. The operating and maintenance costs of the system are assumed to be $0.05 per kL of rainwater used;
- The price of mains water is $0.94 per kL and wastewater discharge is charged on the basis of mains water use at $0.203 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:

- The Maryville rainwater supply system;
- The Maryville rainwater supply with a $35 annual rate rebate from local government;
- The Maryville rainwater supply system with a $35 per year rate rebate from local government, a $960 saving in new stormwater infrastructure costs (Chapter 2) and a saving of $500 on new water supply infrastructure costs.

The present value and cost of rainwater for each scenario is shown in Appendix F and summarised in Table 3.5.

Table 3.5: Economic analysis of the rainwater supply system at the Maryville house

Scenario	**Annual water and saving ($)**	**Annual costs ($)**	**Present value ($)**	**Cost of rainwater ($/kL)**
RSS	70.87	22.19	-918	0.30 (cost)
RSS + $35 annual rebate	70.87	22.19	-248	0.08 (cost)
RSS + infrastructure savings + $35 annual rebate	70.87	22.19	1212	0.39 (benefit)

The cost of rainwater at the Maryville house is estimated to be $0.30/kL (Table 3.5), 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 value cost of $918 may be a disincentive for the resident to install a rainwater tank.

The installation of Maryville rainwater tank has reduced stormwater discharges to the downstream environment. This will result in benefits accruing to residents downstream of the Maryville house. 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 reduce the cost of rainwater to $0.08/kL.

The installation of the rainwater tank has reduced stormwater peak and volumetric discharges, and peak and volumetric water demands. The widespread installation of rainwater tanks may reduce the need for new stormwater and water supply infrastructure resulting in reduced construction costs to the land developer. With the inclusion of a stormwater infrastructure saving of $960 as determined from the Figtree Place development (Chapter 2) and an assumed water supply infrastructure saving of $500 the benefit of the rainwater supply system will be $0.39/kL.

Even without rebates the cost of water supply from a rainwater tank appears to be significantly less expensive than the price of mains water in the Lower Hunter region. Clearly rainwater supply can be competitive with 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 provided a 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.

3.5 Summary

The design, construction and performance of the dual water supply system at the Maryville house were examined in this Chapter. A design was developed for the installation of a rainwater tank to supply rainwater for toilet, hot water and outdoor uses. The rainwater supply was supplemented with mains water via a trickle top system when water levels are low in the tank. An air gap was used for backflow prevention in accordance with Australian standards.

Monitoring of the performance of the dual water supply system at the Maryville house revealed that use of the rainwater tank reduced stormwater volumetric (39%) and peak discharges (86%), and mains water maximum daily (80%), peak instantaneous (94%) and volumetric (52%) demands. The dual water supply system was installed at a cost of $1,851, which is considerably less than the commonly assumed cost of over $4,000. The cost of rainwater supply 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 were considered. This is significantly less than the $1 - $14 per kL cost of rainwater reported by industry. The cost of the rainwater supply at the Maryville house appears to be significantly less expensive than the price of mains water in the Lower Hunter region. Rainwater supply can be economically competitive with the mains water supply, although it must be stressed that the mains water system provides drought security.

Monitoring of water quality from the rainwater tank and from the 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 (Chapter 2) the quality of runoff from the roof was found to improve in the rainwater tank and the hot water service. The quality of the hot water was found to be similar at Figtree Place and Maryville experiments. The quality of rainwater stored in the Maryville tank was found to be generally better than the rainwater stored in the Figtree Place tanks because the rainwater tank at Maryville was in better structural condition than the rainwater tanks at Figtree Place.

The results from the Maryville experiment indicate that the installation of a rainwater tank will provide significant benefits to the community. However the Maryville house has a small roof area and is situated on a small inner city allotment that is close to heavy industry. Average daily water use at the Maryville house (309 L) is less than the HWC average daily indoor water use (444 L) and from a three-person household at Figtree Place (560 L). Houses with greater water consumption and larger roof areas may experience greater mains water savings and increased stormwater discharges. Houses that are further from industry may have even better roofwater quality. The performance of the Maryville house was monitored over a short time period that did not include drought conditions. An analysis to determine the impact of widespread installation of rainwater tanks will need to evaluate the long-term performance of a variety of dwellings that use water from rainwater tanks to supplement mains water supply.

This Chapter concludes the experimental study of source controls at the allotment scale. It is already clear that the widespread installation of rainwater tanks is likely to significantly reduce the requirement for new dams, water supply and stormwater drainage infrastructure. The remainder of the thesis will take up the challenge of more comprehensively evaluating the benefits of rainwater tanks to the community and the environment.

Water quality and health standards are examined in more detail in Chapter 4 and institutional resistance to the use of rainwater tanks is examined in Chapter 5. In Chapter 6 a water balance model is developed to simulate the long-term performance of houses and clusters with rainwater tanks including the Maryville house and the Figtree Place development. Chapter 7 examines the impact of source control measures including rainwater tanks on stormwater drainage infrastructure in land subdivisions. The impact of widespread installation of rainwater tanks on the water supply headworks schemes in the Lower Hunter and Central Coast regions is examined in Chapter 9.

The costs of installing rainwater tanks is combined with stormwater infrastructure savings from Chapter 7 and water supply headworks savings from Chapters 9 in a whole-of-water cycle economic analysis in Chapter 10.