Chapter 2

The Figtree Place Experiment

> "In order to promote a sustainable approach to urban drainage infrastructure provision, there is a need to go back to basics and copy nature's way. Nature has evolved balanced hydrological and hydro-geological cycles with relatively slow dynamics. Rainfall runoff response in nature is relatively slow on account of natural flow brakes and distributed storage provided by flora and habits of fauna ….." Bob Andoh and C. Declerck [1999].

2.0 Introduction

The Figtree Place re-development, consisting of 27 residential units located in Hamilton, an inner suburb of Newcastle, is an experiment in the use of WSUD source control measures for water supply and stormwater management. The project is a re-development of a portion (0.6 ha) of the Hamilton Bus Station (3.0 ha) initiated by Newcastle City Council (NCC) and the New South Wales Department of Housing. The Australian Government's Building Better Cities Program provided funding for construction of the development.

Construction of the Figtree Place development was completed in 1998. The site is managed by Newmacq Community Housing Company to provide affordable housing for the Newcastle community. A program to monitor performance of the development was funded by NCC and the New South Wales Government Stormwater Trust.

This chapter describes the WSUD concept and the source control measures constructed at Figtree Place. It details the institutional resistance, construction errors and social issues encountered during the project. The monitoring program is presented and the performance of the WSUD source control measures is discussed.

2.1 The WSUD Concept

The water sensitive design elements at Figtree Place include underground rainwater tanks, gravel filled trenches (soakaways), a recharge basin and a submerged pump in the aquifer. A general plan of the site and the water sensitive design elements is shown in Figure 2.1.

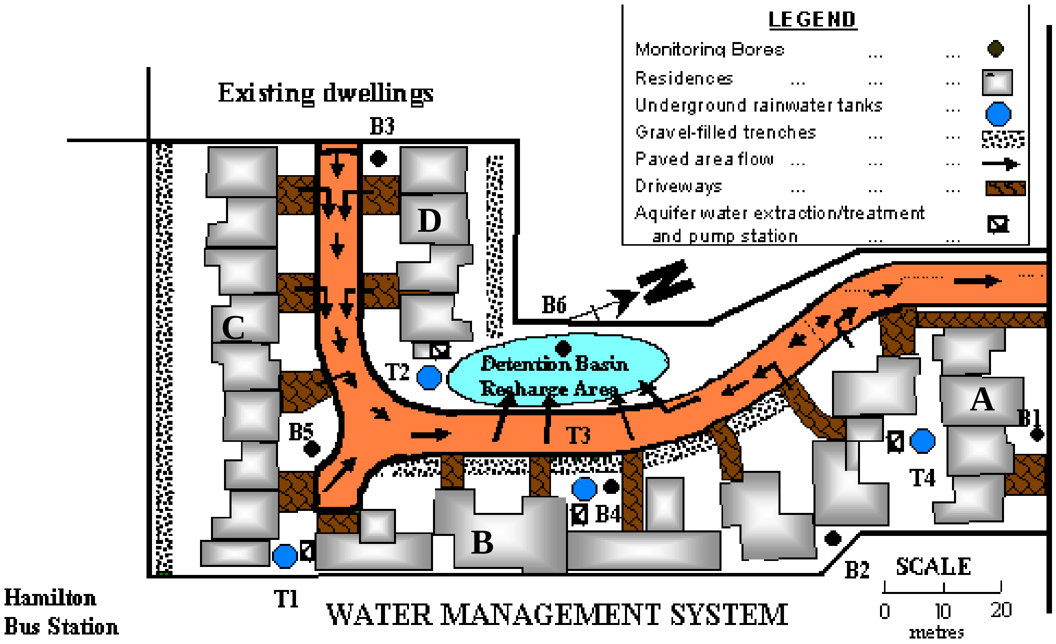

Figure 2.1: General plan and water sensitive design elements of Figtree Place

The Figtree Place water sensitive design concept is detailed in Figure 2.2. Rainwater collected from roofs flows via stormwater pipes through a first-flush pit into a rainwater storage tank. Pumps with pressure cells supply rainwater from tanks for use in hot water systems and for toilet flushing. If a rainwater tank's capacity is exceeded overflow is directed to a gravel trench and recharged to the aquifer.

Stormwater runoff from paths, lawns and gardens is directed into the detention basin via internal roadways (Figures 2.1 and 2.2). Stormwater is then recharged to the aquifer from the detention basin. Groundwater is supplied using a submerged pump for irrigation on site and bus washing at the Hamilton Bus Station.

The first-flush pit (Figure 2.3) was designed to separate an initial portion of roof runoff containing higher concentrations of pollutants from inflow to rainwater tanks. There is limited research on defining the quantity of first flush separation producing acceptable water quality in rainwater tanks. Jenkins and Pearson [1978] suggest separating the first 0.25 mm of rainfall for a typical sized household roof. First flush pits at Figtree Place were conservatively designed to divert the first 2 mm of rainfall from the inflow to the rainwater tank due to a concern that industrial fallout on roofs and subsequent wash off would contaminate stored rainwater and a requirement to expedite development application approval from Newcastle City Council.

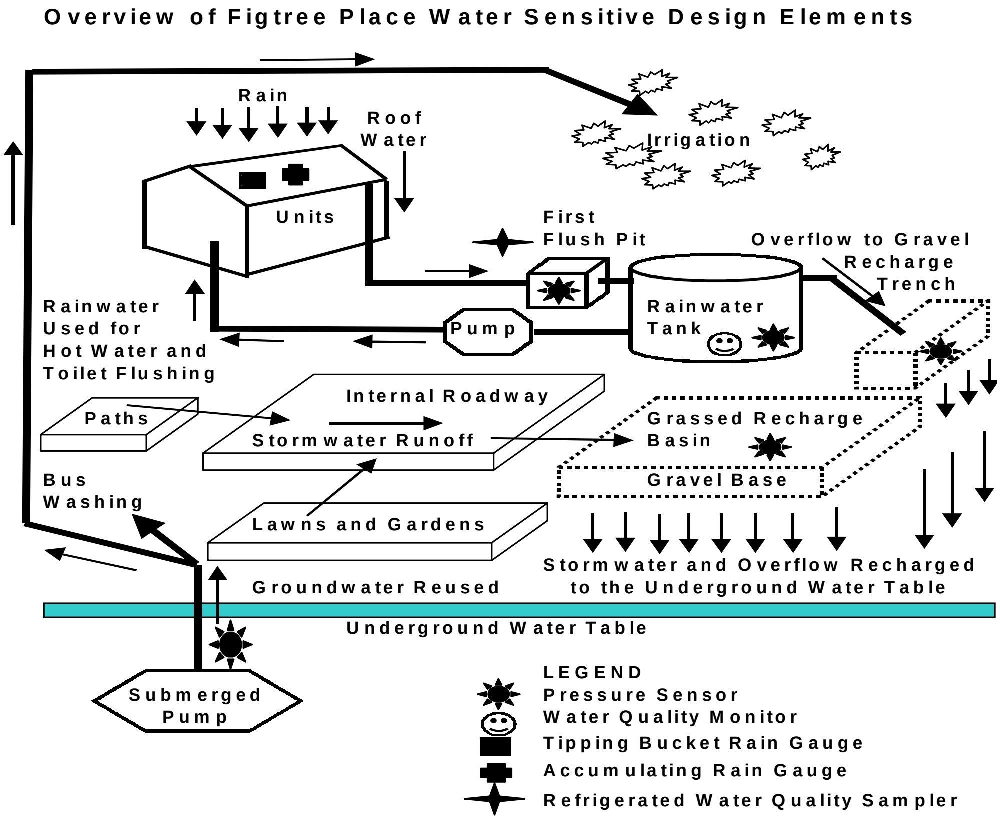

Figure 2.2: The Figtree Place Water Sensitive Design Concept

First-flush pits were constructed using a reinforced concrete box placed over a fibre reinforced concrete pipe. The concrete box contains a screen to filter debris from the roofwater flow and a baffle to separate first flush from inflow to the rainwater tank. Roofwater retained upstream of the baffle infiltrates through holes in the base of the box to the pipe and into the soil.

Reinforced concrete rainwater tanks (Figure 2.4) are used at Figtree Place. The four rainwater tanks are rectangular with capacities ranging from 10 kL to 20 kL. Rainwater tanks contain an inlet from a first flush pit, a clean out chamber for removal of sludge, a low water level monitor, an outlet for domestic supply and an overflow pipe to a recharge trench. The low water level monitor allows water to be drawn from mains supply if the water level in a tank is low.

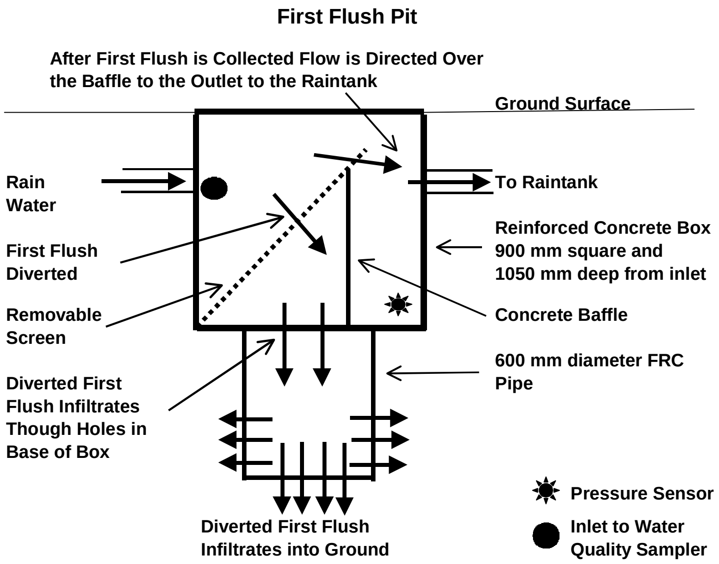

Figure 2.3: Diagram of a first flush pit

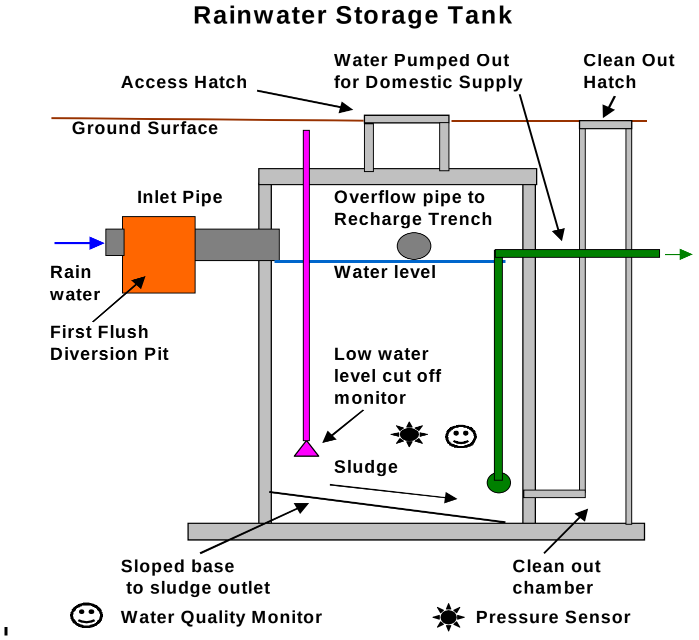

Figure 2.4: Diagram of a rainwater storage tank

Recharge trenches were constructed as 750 mm deep and 1000 mm wide layers of gravel enclosed in geofabric below 300 mm topsoil layers. Overflow from rainwater tanks is conveyed to recharge trenches by stormwater pipes and distributed within the trenches by slotted pipes.

The recharge basin (Figure 2.5) is a grassed depression with an area of 300 m^2 that overlays a 750 mm layer of gravel enclosed in geofabric. All surface stormwater runoff is directed to the basin and the high infiltration rates of the sandy soil are exploited to minimise overflows from the basin. The infiltration basin was designed to prevent stormwater overflows to Denison Street up to the 50-year average recurrence interval (ARI) storm event. A submerged pump supplying groundwater for irrigation and bus washing is situated within the recharge basin at a depth of 10 metres.

Pumps with pressure vessels are situated in pump houses adjacent to each rainwater tank (Figure 2.1). Each pump house has a number of fail-safe water supply systems. These include a second pump to operate in case of pump failure and a solenoid that switches water supply from tank water to mains supply if inadequate water pressure is detected, electricity supply is interrupted, or if a low water level is detected in a rainwater tank. The provision of an additional pump at each tank was a conservative and unnecessary measure motivated by the approval authority's concern about the reliability of rainwater supplies. Pump failure was not a critical issue at the Figtree Place because each unit was supplied with mains water in the advent of pump failure.

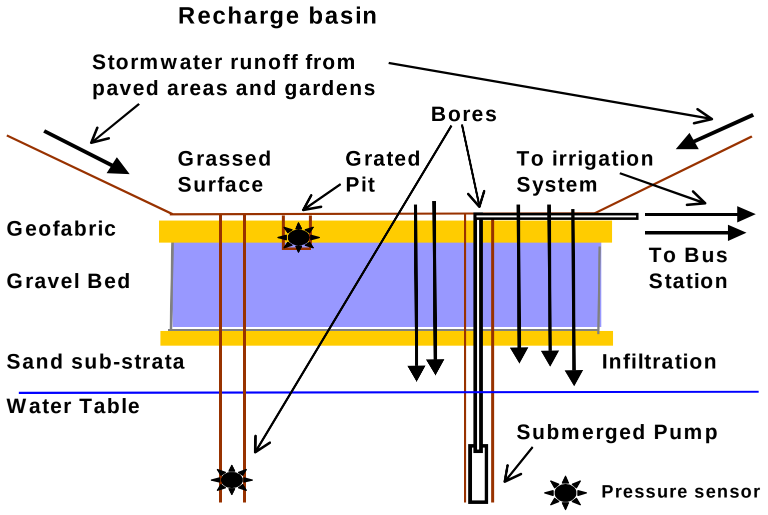

Figure 2.5: Diagram of the recharge basin

2.2 Institutional Resistance and Construction Errors

The development of the Figtree Place project began in 1995 with a concept design by John Argue [Argue, 1997]. Institutional resistance to the water sensitive design and many construction errors adversely affected development and operation of the project. This Section describes this process in order to demonstrate the need for good will, commonsense and careful supervision of contractors when developing new ideas.

At the commencement of the concept design for Figtree Place in 1995, John Argue held meetings with the Newcastle Public Health Unit (PHU), and the NSW Environment Protection Authority (EPA). A draft report of the concept was subsequently provided to the EPA, the NSW Department of Land and Water Conservation (DLWC) and the Hunter Water Corporation (HWC) [Argue, 1997].

The representative of the PHU explained that it was important to maintain public health although he accepted that the risk of water shortages highlighted the need to trial, monitor and learn from innovative water management techniques including the use of rainwater. He claimed that a progressive outlook on rainwater use was not common at the PHU [Argue 1997]. The PHU required monitoring of water from rainwater tanks and from hot water systems, and the assurance that mosquitoes would be excluded from entry to rainwater tanks.

The EPA expressed concern that the Figure Place project was to be located on a contaminated site that had been subject to remediation [EPA, 1995]. Infiltration measures used for stormwater management were expected to expose downstream waterways and ground waters to the threat of contamination. Monitoring of groundwater quality was required. A further concern of the EPA was that failure of the infiltration strategy that resulted in contamination of waterways or groundwater would bring alternative water management techniques into disrepute.

The DLWC process license applications for bores that will extract groundwater. A representative of the DLWC explained that not all applications for groundwater extraction licenses were successful. However an application that included an annual balance of aquifer recharge and retrieval would be viewed favorably [Argue, 1997]. The DLWC representative was also concerned that the groundwater may be saline and therefore unsuitable for irrigation purposes at Figtree Place.

The representative from the HWC claimed that roof runoff carried high levels of microbial and chemical contamination that, even with the provision of first flush devices, could pose serious health risks when used inside the house [HWC, 1995]. He accepted that heating rainwater in hot water systems had the potential to eliminate bacteria but insisted that hot water may find potable uses and regular testing for microbial and chemical contamination was therefore required.

To ensure that HWC complies with its operating license to supply water that meets the Australian Drinking Water guidelines [NHMRC, 1996], no cross connections between bore water or rainwater systems and the mains water supply were permitted at Figtree Place. A testing program was also required for the bore water.

In April 1997, the proposed water management system was rejected by HWC because the design did not meet the HWC requirements in respect to cross connection between alternative and the mains water supply [Seymour, 1997]. The HWC plumber stated that the design did not comply with the requirements of Australian Standards including AS3500.1.2 [1996].

The project architect explained that he had proposed Reduced Pressure Zone Devices (RPZD) for backflow prevention in accordance with the HWC requirements and that a RPZD was recommended for high hazard installations in AS3500.1.2 [Seymour, 1997]. Indeed a cross connection between mains water and effluent from hospitals, laboratories, sewage treatment plants, chemical plants or nuclear installations that is likely to cause death upon ingestion is considered to be a high hazard in Australian Standards [AS3500.1.2, 1996]. Cross connection between water from rainwater tank and mains water is rated as a low hazard.

Regardless of the low hazard classification of cross connections with rainwater in AS3500.1.2 the HWC plumber insisted that such a cross connection was more dangerous than a high hazard rating by rejecting the highest rated backflow prevention device available. This implied that rainwater posed greater health risks than effluent from hospitals, laboratories and so on.

A manager at HWC responded to the project architect’s concerns stating that the appropriate backflow prevention devices must be in place because the corporation did not have the authority or responsibility to control water uses on private property [HWC, 1997]. The original proposal to install RPZD backflow prevention was deemed acceptable if a monitoring and maintenance program was in place to ensure ongoing operation of the devices.

Interestingly, the project architect had earlier rejected the HWC suggestion to use an air gap in the rainwater tanks for backflow prevention [Seymour, 1997]. The HWC suggestion was rejected by the architect because the use of an air gap would require the rainwater tanks to be topped up by mains water. He did not want to top up the rainwater tanks with mains water. The HWC desired the use a physical air gap because it ensured that cross connection could not occur between mains water and rainwater. This solution is recommended for cross connections rated as low to high hazard in the Australian Standards and is simple to install.

Early in 1998, the construction of Figtree Place was considered complete by the Department of Housing and the site was commissioned with tenants subsequently occupying the units. During April 1998, the research program to monitor the performance of the site began. Investigation of the site early in the research program revealed that the construction of Figtree Place was not complete with many of the water management measures not operating as intended. Numerous construction errors were found that appeared to be a result of poor design and supervision of the project, incomplete knowledge of installation processes for WSUD elements and institutional resistance to reuse of rainwater and groundwater. The construction problems included:

- the first flush devices were not installed allowing potentially contaminated roof water into the rainwater tanks;
- the solenoid devices installed to allow switching between mains water and tank water supply only worked intermittently;
- although the contract for the construction of Figtree Place specified rainwater tanks poor quality stormwater detention tanks were installed. These tanks had holes in their sides, lids and roofs allowing soil and debris to enter stored rainwater;
- the stormwater detention tanks still contained construction debris;
- the pumps supplying tank water to the units would frequently lose their prime during periods when the tanks were empty so that they could not operate when the tanks refilled;
- the residents were subject to variable hot water pressures due to incorrect setting of pressure in pumps;

- the roof gutter system was incorrectly installed allowing roof water and debris to be stored in the gutters for long periods potentially compromising tank water quality and
- an infiltration trench was found to be discharging to a rainwater tank further compromising, potentially very seriously, tank water quality.

In August 1998, the site was still not available for installation of monitoring equipment due to a protracted dispute about the construction contract between NCC, the Department of Housing, the contractor and the project architect. Although the NSW Minister for Urban Affairs and Planning had opened Figtree Place and the site was the subject of a number of media articles discussing urban water management none of the agencies were prepared to correct the construction defects to enable the site to operate as reported.

During September 1998, a consulting engineer was engaged to design first flush pits for the site. The Department of Housing installed the first flush pits, redirected overflow from an infiltration trench from a rainwater tank to the central infiltration basin and replaced damaged plumbing. A plumber, a hydraulic engineer and an electrician were employed to correct the rainwater supply system construction errors. The contractors found the following errors:

- The original installation relied on pumps operating on a suction lift resulting in the pumps becoming air locked after operation using mains water because mains pressure was piped into the discharge side of the pump system. This was fixed by connecting mains water pipes to the suction side of the pump.
- The solenoid valves in the original installation were a diaphragm type considered unreliable. These were replaced with a more robust piston type solenoid valve.
- The original installation did not provide an electrical connection between the low water level float and the pump control panel. This resulted in pumps continuing to operate when tanks were empty and the water supply system had switched to mains water supply. The correct connection was provided.
- The electrical wiring in all low-level float switches had been reversed potentially allowing mains water supply when tanks were full rather than when the tanks were empty. This could not eventuate because there was no electrical connection between the low-level control switch and the pump control panel. The wiring was corrected.
- The pumps pressure settings were altered to provide acceptable operating pressure.
- Debris was removed from three of the four tanks.

The temporary nature of the solutions employed to address the construction errors at Figtree Place including the combination of pumps supplying suction lift and solenoid valves to switch between tank and mains water supplies has resulted in unreliable operation of the alternative water supply throughout the project. A permanent solution for the supply of tank water would be installation of a submerged pump in each tank and a mechanical system of ensuring water supply to the hot water system and toilet in each unit. The current system relied on the use of solenoid valves to transfer water supply to the units from mains water to rainwater as required. The solenoid valve arrangement used at Figtree Place was an electronic system that was subject to frequent failures. It is believed that a mechanical system would have been more reliable.

The Department of Housing was not interested in a permanent solution for the alternative water supply system due to the cost of replacing the existing pumps [NCC, 1998]. The damaged stormwater detention tanks and faulty roof gutter system were also not replaced by the Department of Housing. This was likely to compromise the quality of the alternative water supply.

Immediately following the reconstruction of elements of the alternative water supply system a monitoring program was commenced to measure performance of the stormwater and water supply systems. During November and December 1998 it was discovered that the first flush pits had been over designed resulting in the separation of a majority of rainwater prior to entry to the tanks.

The consulting engineer had designed the first flush pits to separate the first two millimetres of the two-year average recurrence interval design (ARI) storm event [IEAust, 1987] from entry to the tanks. Given that the majority of storm events are likely to be smaller than the two year ARI design storm very little water entered the tanks. The size of the first flush pits adjacent to tank T2 (Figure 2.1) was reduced to allow separation of an average of one millimetre of rainfall from all storms. This involved halving the size of the pits. The first flush pits were designed using the Ffpit model developed in Section 6.6. The model continuously simulates the performance of first flush devices using pluviograph rainfall data.

The Figtree Place development is an innovative project that required design and construction techniques that were uncommon and novel. It is important for this type of project to have adequate design documentation, constructing contractors who are sympathetic to the innovative ideals of the project and early involvement of the constructing contractors in detailed design development. A successful project also requires that approval agencies, constructing contractors and designers are acting for the successful completion of the project. A clear understanding of information requirements is also required.

The Figtree Place development had many proponents including Newcastle City Council, the New South Wales Department of Housing, the Office of Community Housing and the Federal Government Building Better Cities Program. The proponents in combination with a multiplicity of approval agencies, designers and construction contractors struggled with conflicting assumptions about domestic use of rainwater and ground water. Indeed the proponents, constructors and designers rarely agreed on design requirements that resulted in inadequate construction of the project. Institutional resistance to the use of rainwater and ground water by individuals within the approval agencies led to construction of redundant elements in the project (such as two pumps for every rainwater tank) and protracted disagreement.

2.3 A Social Survey

Persons seeking community housing were surveyed prior to occupation of the units at Figtree Place to gauge their reaction to the use of rainwater for different household purposes. This Section describes the results of the social survey.

The Figtree Place project was constructed to provide affordable housing to the Newcastle community. Prior to placement in the housing development 26 potential tenants were issued with a questionnaire (Appendix A) that sought opinions on the merit of using mains water, stormwater and rainwater for different purposes. The responses are shown in Table 2.1.

Table 2.1: Responses to the water use questionnaire

Description	**Response (%)**				
Mains water used for:	**Excellent**	**Good**	**Fair**	**Poor**	**Very poor**
Water gardens and lawns	8	52	8	4	28
Hot water	27	50	19	0	4
Toilet flushing	23	42	8	4	23
Clothes washing	19	55	14	4	8
Drinking	27	35	19	0	19
Cooking	27	45	14	0	14
Stormwater collected from paths used for:					
Water gardens and lawns	64	14	14	0	8
Rainwater collected in tanks used for:					
Water gardens and lawns	73	19	0	8	0
Hot water	36	46	4	14	0
Toilet flushing	58	30	8	4	0
Clothes washing	23	40	14	19	4
Drinking	4	19	27	8	42
Cooking	8	35	14	8	35

The potential tenants were issued with the questionnaire following acceptance for community housing and before introduction to the Figtree Place development. In the questionnaire the tenants were asked to rank mains water, stormwater and rainwater use for various domestic purposes. For example Table 2.1 shows that 8% of respondents believed that mains water use to water gardens and lawns was an excellent idea. One of the respondents had lived in a house with water supply from a rainwater tank prior to answering the questionnaire, two respondents use hot water for clothes washing and 48% of the respondents use water from the hot water tap for cooking. None of the respondents drank water from the hot water tap.

By grouping the excellent and good ratings from Table 2.1 together a measure of approval of stormwater and rainwater reuse was developed. Similarly a grouping of the poor and very poor ratings from Table 2.1 was combined to create a measure of disapproval. The results are shown in Table 2.2.

Table 2.2: Approval ratings for domestic use of stormwater and rainwater

Description	**Response (%)**	
Mains water used for:	**Approve**	**Disapprove**
Water gardens and lawns	60	32
Hot water	77	4
Toilet flushing	65	27
Clothes washing	74	12
Drinking	62	19
Cooking	72	14
Stormwater collected from paths used for:		
Water gardens and lawns	78	8
Rainwater collected in tanks used for:		
Water gardens and lawns	92	8
Hot water	82	14
Toilet flushing	88	4
Clothes washing	63	23
Drinking	23	50
Cooking	43	43

Table 2.2 clearly shows that the Figtree Place tenants accepted the use of stormwater for watering gardens and lawns, and rainwater for watering of gardens and lawns, toilet flushing, hot water and clothes washing. The limited sample size and the non-randomised selection of respondents do not permit extrapolation to the wider community. Nonetheless the results are indicative of wider community views.

The concerns of the PHU and HWC about the risk of ingestion of rainwater used in hot water systems seem to be overstated given that none of the respondents drank from the hot water tap. However the finding that 48% of respondents used water from the hot water tap for cooking highlighted the need to ensure that rainwater used in hot water systems was compliant with drinking water standards. A monitoring program for water quality is described in Section 2.4 and the water quality results are presented in Section 2.5. The issues of water quality and health risks will be discussed further in Chapter 4 and the discussion on institutional resistance to rainwater reuse will continue in Chapter 5.

2.4 The Monitoring Program

A monitoring program was commissioned to assess water quality, water use, maintenance issues and economic performance at Figtree Place. Manual and automated monitoring programs were developed and are discussed below.

A manual sampling program was used to assess water quality measured from the roofs, first flush pits, rainwater tanks and hot water systems on a monthly basis. Table 2.3 summarises the microbial and chemical parameters monitored at Figtree Place and the guideline values recommended by the Australian Drinking Water Guidelines [NHMRC 1996].

Accumulating and tipping bucket rain gauges paired at two different sites measure rainfall. Roof water was collected on an event basis from roofs using 50 L plastic containers connected to downpipes. An automated sampling program using a refrigerated water quality sampler drawing roof water from a first flush pit (Figure 2.3) was used to verify manual sampling results and to permit sampling of roof water quality throughout a storm event.

Table 2.3: Water quality parameters monitored at Figtree Place

Chemical		**Microbial**	
Characteristic	**Guideline**	**Characteristic**	**Guideline**
Ammonia	0.5 mg/L	Total Coliforms (TC)	0 mg/100 L
Nitrite	50 mg/L	Fecal Coliforms (FC)	0 mg/100 L
Nitrate	3 mg/L	Hetroterophic Plate Count (HPC)	Not Given
Total Suspended Solids	500 mg/L	Pseudomonas Species (Ps)	Not Given
Total Dissolved Solids	500 mg/L	Cryptosporidium	Not Given
Chloride	250 mg/L	Giardia	Not Given
Iron	0.3 mg/L		
Lead	0.01 mg/L		
Cadmium	0.002 mg/L		
Sodium	180 mg/L		
Calcium	200 mg/L		
Zinc	3 mg/L		
pH	6.5 - 8.5		
Sulfate	250 mg/L		

An automated sampling site was established at a pump house adjacent to the western rainwater tank (shown as T2 in Figure 2.1). The site (Figure 2.2) uses a data logger, a tipping bucket rain gauge, pressure sensors, a water quality monitor and a refrigerated water quality sampler. The data logger controls monitoring and recording processes according to the flowchart shown in Figure 2.6.

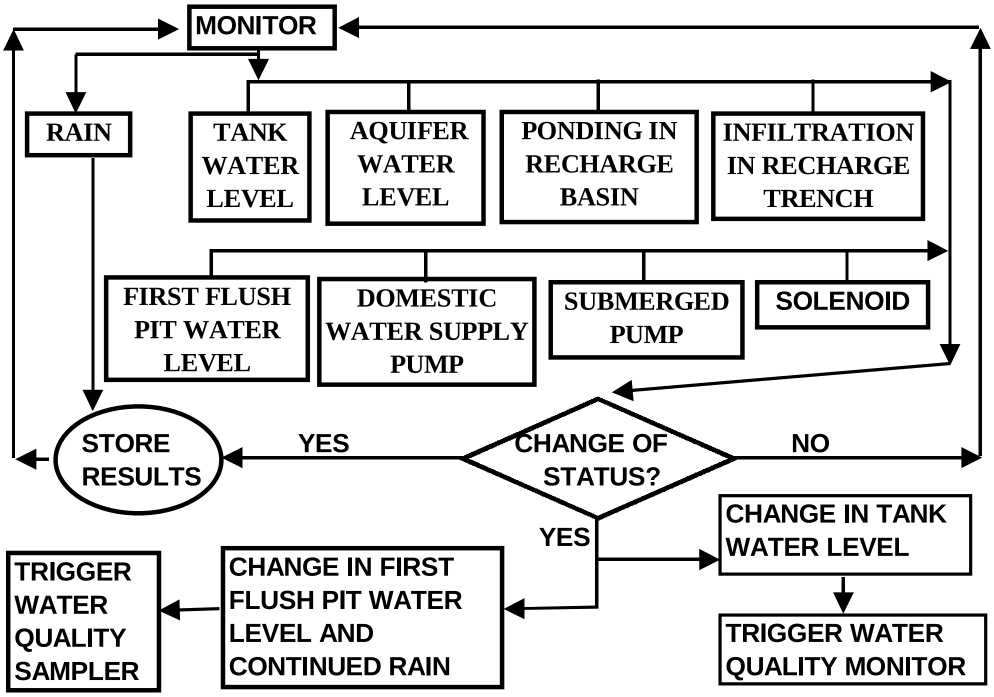

Figure 2.6: Automated monitoring flowchart

Pressure sensors were used to measure water levels in the first flush pit (Figure 2.3), in rainwater tanks (Figure 2.4) and in groundwater bores (B1-B6 in Figure 2.1). Pressure sensors were also placed in a small pit with a grate cover in the recharge basin (Figure 2.5) to measure ponding and in a slotted pipe standing upright within the gravel layer in the recharge trench to measure infiltration. The water quality monitor measures temperature, pH, DO, conductivity, turbidity and salinity of the water in the rainwater tanks.

2.5 Rainwater Quality from Roofs, Tanks and Hot Water Services

Rainwater collected from roofs and stored in four rectangular reinforced concrete tanks (10 kL – 20 kL) was used to meet hot water and toilet flushing demand at Figtree Place. Rainwater quality from roofs, tanks and hot water systems was monitored for a period of two years.

Site inspections following the commissioning of Figtree Place revealed many construction errors (see Section 2.2). Stormwater detention tanks had been installed rather than rainwater tanks. There were many holes and cracks in the walls of the stormwater detention tanks allowing debris, soil and leaves to fall into the tanks from the surrounding garden beds. Ponding in the roof and gutter system had also resulted from poor construction practices and was expected to further compromise water quality.

Although these construction errors were expected to significantly compromise tank water quality, the sampling program was nevertheless commenced to assess this “worst-case” scenario. To further test the “worst-case” scenario the roof gutter system was not cleaned. This section describes the monitoring results from the roofs, tanks and hot water systems at Figtree Place.

Samples collected from roofs, tanks and hot water systems were tested for the parameters shown in Table 2.3. Bacterial enumerations were conducted with 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 B.

2.5.1 Rainwater Quality

The average, maximum and minimum values of parameters for rainwater collected in the open at Figtree Place are shown in Table 2.3. Samples were collected in sterile beakers placed on a roof for the duration of 14 storm events during the winter and spring seasons of 1998 and 1999. The measured parameter values were compared to Australian Drinking Water Guidelines [NHMRC, 1996] (shown as "Guideline" in Table 2.3). The rainwater samples complied with the guidelines with the exception of pH and Lead. The average value for pH of 6.05 was lower than the range (6.5 – 8.5) shown in the guidelines and similar to the results shown in Yaziz et al. [1989]. There was one exceedance of the Guidelines for lead.

The rainwater samples contained Heterotrophs and *Pseudomonas Spp.*, which are common in natural aqueous environments. Heterotrophs use organic chemicals as a principal carbon source. Heterotrophic Plate Counts can be used to determine the presence of organic matter in water and as an indicator of general water quality. *Pseudomonas Spp.* is dependent on a regular source of nutrients and can form biofilms. *Pseudomonas Spp.* was used to indicate the presence of nutrients in water and of biofilms on surfaces.

Table 2.4: Rainwater quality at Figtree Place: composite samples from 14 storm events

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	3	6	0	NA
Pseudomonas Spp.	CFU/100 ml	5200	10400	0	NA
Sodium	mg/L	9.55	63.8	0.1	180
Calcium	mg/L	7.09	80.6	0.06	200
pH		6.05	6.4	5.5	6.5 - 8.5
Dissolved solids	mg/L	21	34	8	500
Suspended solids	mg/L	8.4	8.4	8.4	500
Chloride	mg/L	8.4	24.2	0.4	250
Nitrate	mg/L	0.1	0.2	<0.05	3
Nitrite	mg/L	0.73	2.4	<0.02	50
Sulphate	mg/L	3.48	5.9	0.8	250
Ammonia	mg/L	0.22	0.4	0.05	0.5
Lead	mg/L	<0.01	0.15	<0.01	0.01
Zinc	mg/L	<0.01	<0.01	<0.01	3
Iron	mg/L	<0.01	<0.01	<0.01	0.3
Cadmium	mg/L	<0.002	<0.002	<0.002	0.002

2.5.2 Rainwater Quality from Roofs

Rainwater was initially sampled from roofs at Figtree Place using manual collection at downpipes connected to roof sections with different aspects in conjunction with David Arthur, Howard Bridgeman and Chris Dever from the Department of Geography and Environmental Sciences at the University of Newcastle. Rainwater was subsequently collected using an automated sampler connected to an entire roof area. The results of both methods are discussed in the following sub-sections.

2.5.2.1 Manual Samples Taken From Different Roof Aspects

Roof water was collected in the form of bulk (fifty L containers) and first flush (first 2 mm of rain) samples from the down pipes at five different roof aspects (north-west, south-west, south, east and north) from 19 rain events in the winter of 1998. Bulk samples from 6 rain events were also collected during the autumn of 1999. The samples were analysed for compliance with the chemical Guidelines listed in Table 2.3. The samples complied with the guidelines except for the parameters Ammonia, pH, Chloride, Sodium and Nitrate. A sample from each roof aspect was also tested for contamination by *Cryptosporidium* and *Giardia*, but no protozoa were detected in the samples.

Analysis of roof water collected during the Winter of 1998 from 20 rainfall events revealed the following Guideline exceedences for “first-flush” samples: Ammonia (63% of samples), pH (75%), Chloride (6%), Sodium (6%) and Nitrate (33%). Analysis of the bulk samples showed that Guideline values were exceeded as follows: Ammonia (29%), pH (84%) and Nitrite (5%). A summary of average values for the chemical parameters from the first flush and bulk samples is shown in Table 2.5.

Table 2.5: Average values of chemical parameters from the winter 1998 samples

Parameter	**First flush (mg/L)**	**Bulk (mg/L)**	**Difference (%)**
Chloride	45.6	14.89	67
Sulphate	48.9	9.05	81
Nitrite	2.1	0.33	84
Nitrate	2.9	2.0	31
pH	6.2	6.17	-
Sodium	25.3	7.19	72
Ammonia	1.70	0.52	69
Magnesium	3.80	1.13	70
Calcium	13.1	5.56	58

The results (Table 2.5) demonstrate that a greater proportion of the chemical contamination is in the first flush samples. The source of this chemical contamination is dry deposition on roof surfaces of pollution from the adjacent bus depot, surrounding roads and the heavy industry in the area as well as Chloride deposition from winds originating from the Tasman Sea. Separation of the “first-flush” of roof water from entry to rainwater tanks is likely to improve tank water quality by removing up to 84% of chemical contaminants. The reduced concentrations of contaminants in the bulk samples may also be due, in part, to greater dilution of contaminants in the bulk sample.

Roof water collected during the autumn of 1999 from 6 rainfall events revealed the following Guideline exceedences for bulk samples: Ammonia (43%), pH (67%) and Nitrite (3%). The winter 1998 and autumn 1999 results are compared in Table 2.6.

Table 2.6 shows that the bulk sampled parameter values for autumn 1998 are up to 150% higher than the winter 1998 values. The higher chemistry results for the 1999 data are likely to be a seasonal effect resulting from different weather patterns and higher temperatures.

Table 2.6: Average values of chemical parameters from winter 1998 and autumn 1999

Parameter	**Winter 1998 (mg/L)**	**Autumn 1999 (mg/L)**	**Difference (%)**
Chloride	14.89	22.2	49
Sulphate	9.05	10.2	13
Nitrite	0.33	0.5	52
Nitrate	2.0	2.2	10
pH	6.17	6.5	-
Sodium	7.19	13.4	86
Ammonia	0.52	1.3	150
Magnesium	1.13	2.3	103
Calcium	5.56	6.0	8
TSS	19.5	25.3	30

2.5.2.2 Automated samples taken from a Figtree Place roof

Rainwater runoff from a Colourbond roof (area=340 m^2) was continuously collected before entry to a first flush pit using a refrigerated water quality sampler to allow determination of roof water quality throughout eleven storm events during 1999, 2000 and 2001. Average values of parameters measured at different ranges of accumulated rain depths are shown in Table 2.7 and compared to the guideline values.

Table 2.7: Average rainwater quality from a roof at Figtree Place

		Rain Depth (mm)							
Parameter	**Unit**	**<0.5**	**0.5 - 1**	**1 - 2**	**2 - 3**	**3 - 4**	**4 - 6**	**>6**	**Guideline**
Fecal Coliforms	CFU/100 ml	168	316	105	55	68	36	41	0
Total Coliforms	CFU/100 ml	552	504	253	190	259	143	261	0
Heterotrophic Plate Count	CFU/ml	1775	926	792	992	992	3099	952	NA
Pseudomonas Spp.	CFU/100 ml	117411	62613	17743	19550	7744	88937	34775	NA
Suspended solids	mg/L	49.63	42.25	74.49	46.65	16.20	9.23	2.51	500
Dissolved solids	mg/L	75.22	47.97	42	27.49	49	59.98	71.10	500
pH		5.60	5.68	5.86	5.66	5.88	5.74	6.01	6.5 - 8.5
Chloride	mg/L	21	18	19.80	10.56	12.04	13.23	17.40	250
Nitrate	mg/L	0.87	0.11	0.15	0.15	0.10	0.14	0.20	3
Nitrite	mg/L	3.29	3.02	2.64	1.46	1.13	1.90	0.36	50
Sulphate	mg/L	10.31	6.73	7.21	4.13	8.83	5.13	1.81	250
Calcium	mg/L	4.47	2.69	2.74	1.20	2.95	2.05	0.78	200
Sodium	mg/L	15.70	6.73	16.26	7.16	7.77	9.35	4.87	180
Ammonia	mg/L	0.42	0.40	0.56	0.38	0.21	0.29	0.20	0.5
Lead	mg/L	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01
Zinc	mg/L	1.06	0.76	0.67	0.33	0.40	0.27	0.38	3
Iron	mg/L	0.06	<0.01	0.12	<0.01	0.06	<0.01	<0.01	0.3
Cadmium	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002

The Fecal Coliforms, Total Coliforms and pH values exceeded the guidelines at all stages during the rain events and the lead values exceeded the guidelines at rain depths of < 0.5 mm and 3-4 mm. The exceedance of the guidelines for Fecal Coliforms and Total Coliforms may be caused by build up of debris in the roof gutter system that has not been cleaned in over two years. The exceedance of guidelines for lead could be attributed to exhaust emissions from the surrounding bus depot and the nearby major roads. All other parameters were shown to comply with the guidelines and roof water quality improves as rain depth increases. The results are important in that they provide a rational basis for determining the impact of separating the first flush of rainfall. For example it can be seen in Table 2.7 that the separation of roof runoff generated by the first 1 mm of rainfall from entry to a rainwater tank should significantly improve the quality of tank water.

2.5.3 Rainwater Quality in Stormwater Detention Tanks at Figtree Place

Rainwater was sampled at two locations within the stormwater detention tanks. Samples were taken at the water surface in the stormwater detention tanks and from a pump that draws rainwater at a depth of about 0.5 m in the tank to supply the units at Figtree Place.

The average, maximum and minimum parameter values for rainwater stored in the stormwater detention tanks at Figtree Place are shown in Tables 2.8 and 2.9. Results from 27 samples taken from the water surface of the tanks (Table 2.8) show that the average values for Fecal Coliforms, Total Coliforms and pH exceed the drinking water guidelines. All other parameters are compliant with the guidelines except for a maximum value of Ammonia that exceeded the guidelines.

Water quality at the water surface in the rainwater tank (Table 2.8) was found to improve in comparison to the quality of roofwater (Table 2.7) with the exception of the Total Coliforms, Heterotrophic Plate Counts, Dissolved Solids and Zinc. Greater concentrations of Total Coliforms, Heterotrophic Plate Counts, Dissolved Solids and Zinc were found at the tank water surface. The increased bacterial contamination and Dissolved Solids at the tank water surface (Table 2.8) in comparison to the roofwater quality appears to result from debris, soil and leaves falling into the damaged stormwater detention tanks. Zinc may be accumulating at the tank water surface.

Table 2.8: Water quality at the water surface in the stormwater detention tanks at Figtree Place (based on 27 samples)

Parameter	Unit	Average	Maximum	Minimum	Guideline
Fecal Coliforms	CFU/100 ml	119	800	0	0
Total Coliforms	CFU/100 ml	834	6840	0	0
Heterotrophic Plate Count	CFU/ml	3256	30780	10	NA
Pseudomonas Spp.	CFU/100 ml	6768	33200	0	NA
Temperature	^{0}C	18	21	14	NA
Sodium	mg/L	5.03	19.73	1.61	180
Calcium	mg/L	7.04	17.68	1.20	200
pH		6.15	7.11	4.40	6.5 - 8.5
Dissolved solids	mg/L	102.00	453.00	7.00	500
Suspended solids	mg/L	1.28	6.00	0.20	500
Chloride	mg/L	7.19	19.30	3.40	250
Nitrate	mg/L	0.06	0.32	<0.05	3
Nitrite	mg/L	0.62	2.90	<0.01	50
Sulphate	mg/L	4.93	27.00	2.20	250
Ammonia	mg/L	0.10	0.80	<0.02	0.5
Lead	mg/L	<0.01	<0.01	<0.01	0.01
Iron	mg/L	0.07	0.10	<0.01	0.3
Zinc	mg/L	0.25	1.88	<0.05	3
Cadmium	mg/L	<0.002	<0.002	<0.002	0.002

Water quality results from 6 samples drawn from the point of supply in each tank (0.4m – 0.5m from the bottom of the tanks) revealed (Table 2.9) that only the average values for Total Coliforms and pH exceeded the guidelines.

Average values for the Fecal Coliforms, Total Coliforms, Heterotrophic Plate Counts and Nitrates measured at the point of supply were significantly lower than the corresponding average values obtained from samples at the water surface in the tanks. However, an increased average value for Ammonia was also found at the point of supply in the tanks. The presence of *Pseudomonas Spp.* and Ammonia, both at the surface and the point of supply may indicate that biofilms have formed on the walls of the tanks. The metabolic processes within biofilms can utilise Nitrates and immobilise and entrap bacteria (such as Coliforms and Heterotrophs) creating excesses of Ammonia. It is proposed that biofilms on the tank surfaces may contribute to improving water quality at the point of supply.

The average values of the remaining other parameters measured at the point of supply (Table 2.9) were higher than the corresponding values measured at the water surface (Table 2.8). Of particular significance is the observation that no exceedance of the guidelines for Lead was found in the tanks (Tables 2.8 and 2.9) although Lead values exceeded the guidelines in roof water. This suggests that tank water quality also improves because metal and chemical contaminants settle to the bottom of the tanks where they sorb to sludge. Samples taken from the sludge at the bottom of the tanks show accumulation of Lead (0.033 mg/L) and Iron (0.93 mg/L) supporting the assumption that contaminants settle to the bottom of tanks. A survey of water quality in rainwater tanks in the Namoi Valley in NSW also found improved water quality at the point of supply and that chemicals and metals settled to the bottom of tanks [G. Bell, personal communication, Namoi Valley Public Health Unit, 1998]. Similar results were found in the Boolaroo area of NSW by the Newcastle Public Health Unit [J. James J, personal communication, 1999].

Table 2.9: Water quality at the point of supply in the stormwater detention tanks at Figtree Place (based on 6 samples)

Parameter	Unit	Average	Maximum	Minimum	Guideline
Fecal Coliforms	CFU/100 ml	0	0	0	0
Total Coliforms	CFU/100 ml	127	650	0	0
Heterotrophic Plate Count	CFU/ml	351	912	0	NA
Pseudomonas Spp.	CFU/100 ml	4433	15200	0	NA
Temperature	^{0}C	18	21	14	NA
Sodium	mg/L	5.58	11.39	2.10	180
Calcium	mg/L	9.68	20.92	1.40	200
pH		6.03	6.51	5.29	6.5 - 8.5
Dissolved solids	mg/L	129.00	283	39	500
Suspended solids	mg/L	1.37	3.90	0.30	500
Chloride	mg/L	10.38	16.90	4.60	250
Nitrate	mg/L	<0.05	<0.05	<0.05	3
Nitrite	mg/L	0.90	1	0.20	50
Sulphate	mg/L	7.53	17.60	2.80	250
Ammonia	mg/L	0.11	0.20	<0.05	0.5
Lead	mg/L	<0.01	<0.01	<0.01	0.01
Iron	mg/L	0.10	0.10	0.10	0.3
Zinc	mg/L	0.17	0.43	0.06	3
Cadmium	mg/L	<0.002	<0.002	<0.002	0.002

2.5.4 Rainwater Quality in Hot Water Services at Figtree Place

Rainwater stored in the stormwater detention tanks (Tables 2.8 and 2.9) was used to supply electric hot water storage systems (capacity = 250 L) at Figtree Place. The average, maximum and minimum parameter values for water quality in the hot water systems from 14 samples are shown in Table 2.10.

Table 2.10: Water quality from hot water systems at Figtree Place (based on 14 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	3	6	0	NA
Pseudomonas Spp.	CFU/100 ml	0	0	0	NA
Temperature	^{0}C	57	65	50	NA
Sodium	mg/L	4.44	9.80	1.50	180
Calcium	mg/L	10.03	22.90	2.80	200
pH		6.24	7.50	4.70	6.5 - 8.5
Dissolved solids	mg/L	94.43	255.00	2.00	500
Suspended solids	mg/L	0.78	2.00	0.20	500
Chloride	mg/L	10.02	35.10	3.50	250
Nitrate	mg/L	<0.05	<0.05	<0.05	3
Nitrite	mg/L	0.80	3.00	0.05	50
Sulphate	mg/L	9.56	36.40	2.70	250
Ammonia	mg/L	0.18	1.00	<0.01	0.5
Lead	mg/L	<0.01	<0.01	<0.01	0.01
Iron	mg/L	0.02	0.10	<0.01	0.3
Cadmium	mg/L	<0.002	<0.002	<0.002	0.002

Although water supplied from the stormwater detention tanks (Tables 2.8 and 2.9) to hot water systems at Figtree Place exceeded the guideline values for Fecal Coliforms and Total Coliforms, it was found that all coliform bacteria were removed by the hot water system. The pH values remained low, but all the other average parameter values for hot water quality (Table 2.6) complied with the guidelines. The average parameter value for pH (6.24) is marginally lower than the range (6.5 – 8.5) shown in the guidelines. The average value for pH improves from 5.95 in the roof water to 6.24 in the hot water. The average, maximum and minimum temperatures of the hot water samples were 57°C, 65°C and 50°C respectively. The processes of pasteurization and tyndallization (small perturbations of water temperature) apparently act to eliminate Fecal Coliforms, Total Coliforms and *Psuedomonas Spp.* in the hot water systems.

The average and maximum values for the Heterotrophic Plate Counts have been reduced to 3 CFU/mL and 6 CFU/mL respectively. Although the Australian Drinking Water Guidelines [NHMRC, 1996] do not specify a value for this parameter the Japanese and American drinking water guidelines specify 100 CFU/mL [Fujiwara et al., 1992]. The hot water systems at Figtree Place have effectively treated water with bacterial contamination and delivered water compliant with drinking water standards.

The water quality results presented here for Figtree Place represent a “worst case” scenario in which roofwater is collected from poorly installed gutters that were not maintained and stored in damaged stormwater detention tanks. These results suggest that, at a minimum, rainwater tanks can supply water of acceptable quality for toilet flushing and outdoor use and via hot water systems for hot water use. As will be demonstrated in the later chapters this finding has profound implications for management of the urban water cycle.

Other studies show that pasteurization is an effective method of removing bacterial contamination from water. Benenson [1995] reported that *Cryptosporidium* is eliminated within two minutes when water is heated to 60°C and within 20 minutes for water heated to 45°C. Jorgenson et al. [1998] found that Fecal Coliforms are eliminated from naturally contaminated river water when it is heated to 65°C. Joyce et al [1996] found that Fecal Coliforms were eliminated from highly contaminated water (Fecal Coliform count: 200,000 CFU/mL) subjected to a maximum temperature of 55°C over a period of 7 hours.

Monitoring of hot water systems to determine temperatures and operating conditions that may produce bacterial compliance with the Australian Drinking Water Guidelines [NHMRC 1996] was established. Water temperatures from hot water systems with different capacities and operating conditions were measured over a long period. The results from two hot water systems during one week are shown in Figure 2.7.

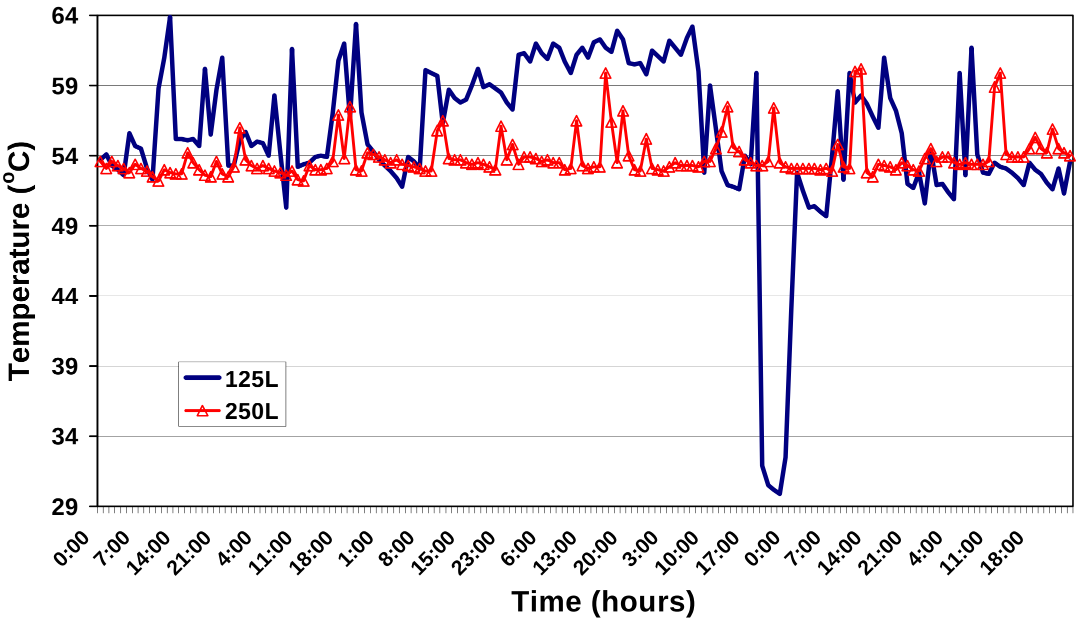

Figure 2.7: Water temperatures from two different hot water systems over a period of a week

The temperature range of an electric 125 litres capacity hot water system set at 60°C that supplies hot water at an off-peak rate to a two person household is shown as 125 L in

Figure 2.7. The off-peak rate heats water from 6 AM to 8 AM and from 8 PM to 10 PM. The average operating temperature was found to be 56°C, the maximum temperature 64.5°C and the minimum temperature 30°C. The low temperature of 30°C resulted from a change in washing mode from showers to a full bath by one of the occupants on one occasion. The capacity and operating mode of the hot water system was insufficient to maintain hot water supply within a temperature range that appears to allow bacterial compliance with guidelines. Removal of the bath event from the data gives a minimum operating temperature of 50.1°C.

The temperature range of an electric 250 L hot water system set at 55°C that supplies hot water at an off-peak two rate to a four person household at Figtree Place is shown as 250 L in Figure 2.7. This hot water system is a component of each unit at Figtree Place. The average operating temperature was found to be 53.7°C, the maximum temperature 60.2°C and the minimum temperature 51.8°C. This hot water system was operating within the range of temperatures that is expected to produce compliance with the drinking water guidelines.

Current Australian plumbing codes require the operation of hot water services at a minimum temperature of 60ºC to inhibit bacterial growth in the hot water system [AS 3666, 1989]. A mixing valve that mixes cold and hot water is required to deliver hot water at 50ºC to a household to minimise the risk of scalding [AS/NZ 3500.4.2, 1997]. This plumbing configuration will allow the use of higher temperatures in hot water services for control of bacteria without increasing the risk of scalding.

2.6 Water Use at Figtree Place

The indoor water consumption of medium density developments and the proportion of indoor consumption that is hot water and toilet use were unknown for the Lower Hunter region. This uncertainty about the water consumption expected at Figtree Place presented difficulties in determining the volume of tanks and capacity of pumps to deliver rainwater to the dwellings during the design of the project. The Figtree Place development consists of 27 units. The units were occupied as follows: 6 units with 1 occupant, 11 units with 2 occupants, 5 units with 3 occupants and 5 units with 4 occupants. This section discusses the water uses monitored at Figtree Place. Monitoring results are shown in Appendix C.

Indoor and outdoor water consumption at Figtree Place was monitored to provide data for the design of future developments that use rainwater to supplement mains water use and to assist in the understanding of the performance of rainwater tanks. Water consumption at Figtree Place was monitored from May 1998 until August 2000 using meters that measured hot water and toilet water use and total indoor water use (see Section 2.7). The recorded monthly daily average consumption and the percentage of consumption that is hot water and toilet use for different numbers of occupants is shown in Table 2.11.

Table 2.11: Monthly daily average consumption and the percentage of total indoor consumption that is hot water and toilet use

Month	**1person (L/day)**		**2 persons (L/day)**		**3 persons (L/day)**		**4 persons (L/day)**	
	Total	**HW + toilet**	**Total**	**HW + toilet**	**Total**	**HW + toilet**	**Total**	**HW + toilet**
Jan	226	61%	387	51%	607	53%	566	48%
Feb	226	61%	369	51%	555	53%	566	48%
Mar	233	61%	397	53%	580	55%	536	47%
Apr	194	57%	349	58%	568	64%	600	62%
May	199	57%	363	61%	590	64%	647	63%
Jun	170	60%	419	65%	559	69%	621	57%
Jul	170	60%	419	65%	559	69%	621	57%
Aug	167	56%	346	60%	418	71%	480	58%
Sep	227	62%	369	60%	526	67%	530	58%
Oct	195	65%	374	61%	538	61%	572	64%
Nov	205	65%	355	60%	611	57%	613	56%
Dec	226	61%	387	51%	607	53%	566	48%

Table 2.11 shows that water consumption at Figtree Place varies from month to month and with the number of occupants. The variation and patterns in water consumption are shown in Figure 2.8. The hot water and toilet use proportion of consumption also varies by number of occupants and from month to month.

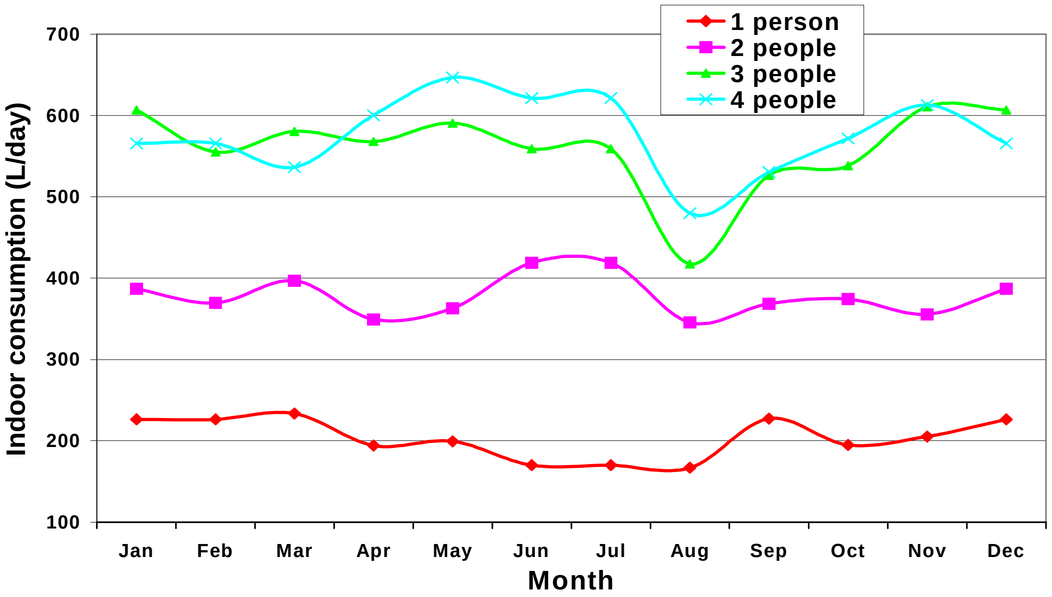

Figure 2.8: Monthly daily average indoor water consumption for different numbers of occupants at Figtree Place

The monthly indoor water use patterns and volumes are shown to be similar for three and four person dwellings and significantly different for single and two person dwellings. The monthly daily average indoor water use at Figtree place and from 130 dwellings monitored in the Lower Hunter region by HWC [B. Berghout, personal communication, 1999] is compared in Figure 2.9.

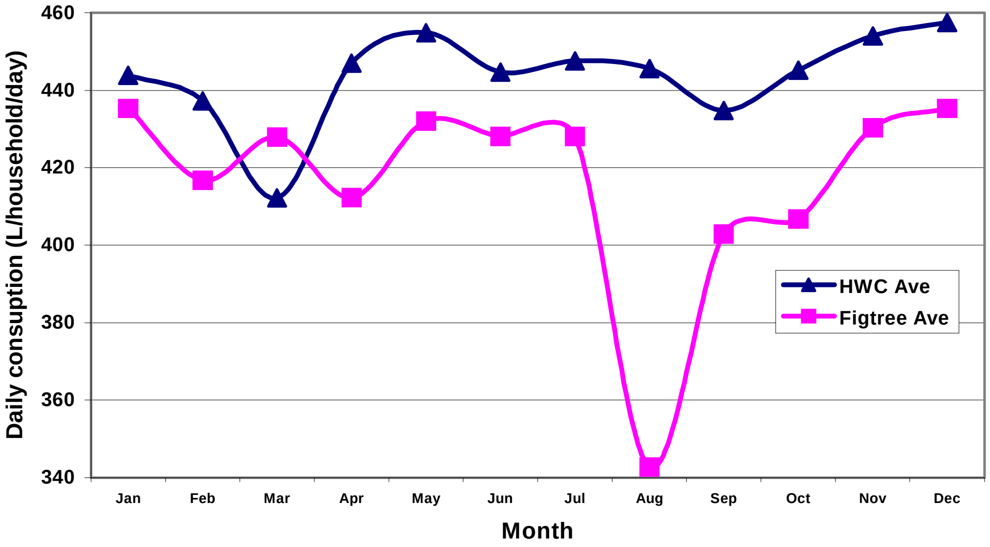

Figure 2.9: Monthly daily average indoor consumption for Figtree Place and the Lower Hunter region

The average water consumption per dwelling at Figtree Place (417 L/day) is less than the average water consumption in the Lower Hunter region (444 L / day). Figtree Place also has different consumption patterns than the Lower Hunter region (Figure 2.9). The different consumption patterns are likely to be the result of different population profiles. Only people with low incomes are permitted to occupy dwellings at Figtree Place. As a result families with young children dominate the occupation of dwellings at Figtree Place. These are mostly single parent families that rely on casual employment. When the parents leave the development to attend employment the children also leave the site to be cared for by relatives or day care centres. It believed that the lower average indoor water use results (Figure 2.9) for the Figtree Place development is due to the frequent absences of parents and children from the site.

In Figure 2.8 it is shown that the average indoor water use for units with 3 and 4 occupants was significantly lower in August than in the surrounding months. This trend is reflected in the overall average indoor water use (Figure 2.9) in August for Figtree Place. The reduced water use in August appears to be caused by families leaving the Figtree Place for the school holidays. Units with 3 or 4 occupants usually contained school age children.

2.7 Performance of the Rainwater Tanks

Although about 15% of Australians use rainwater collected from roofs and stored in tanks for domestic water supplies [ABS, 1994] there is very little information about the performance of rainwater tanks. The interest in rainwater tanks stems from community concern about potential water shortages and stormwater pollution of waterways. Can the use of rainwater tanks in urban areas reduce the demand for water from our rivers and reduce stormwater discharges? This section discusses the performance of the rainwater tanks at Figtree Place. Monitoring results are presented in Appendix C.

There are a small number of published case studies that report the performance of rainwater tanks. The sustainable house in Sydney has four occupants and a 10 kL rainwater tank that collects rainwater from a small roof area of 70 m^2 to supply all indoor uses except toilet flushing [Mobbs et al., 1998]. The tank supplied 230 L / day to the house and required topping up with mains water on four occasions during an 18-month monitoring period. The rainwater tank was able to provide a 53% reduction in mains water use for indoor uses (excluding the toilet). The Stringybark Grove development in Sydney consists of ten townhouses that use roof water stored in a central tank to supply toilet and outdoor uses [Cox and Cartwright, 1998]. A 16% reduction in mains water use was reported.

A desktop study by Mitchell et al. [1997] analysed the performance of houses in Melbourne with roof areas of 203 m^2, three occupants and a 13 kL rainwater tank to supply water for laundry, toilet and outdoor uses. The results indicated that a 30% to 40% reduction in mains water use and 49% to 56% reduction in stormwater runoff were possible. Van Der Wal [2000] found that 65% of rainwater falling on roofs in South Australia could be harvested using standard tank sizes. A house with a roof area of 200 m^2 and an annual rainfall for 555 millimetres was expected to provide a 29% reduction in mains water use.

Water use from the four rainwater tanks at Figtree place was determined by meter readings at each unit and at each tank. Two water meters were installed at each unit. One meter measures hot water and toilet use, and the other measures all other indoor water use. The water meter at each rainwater tank records mains water used to supply hot water and toilets when rainwater was not available from the tank. A schematic of the plumbing and metering system is shown in Figure 2.10.

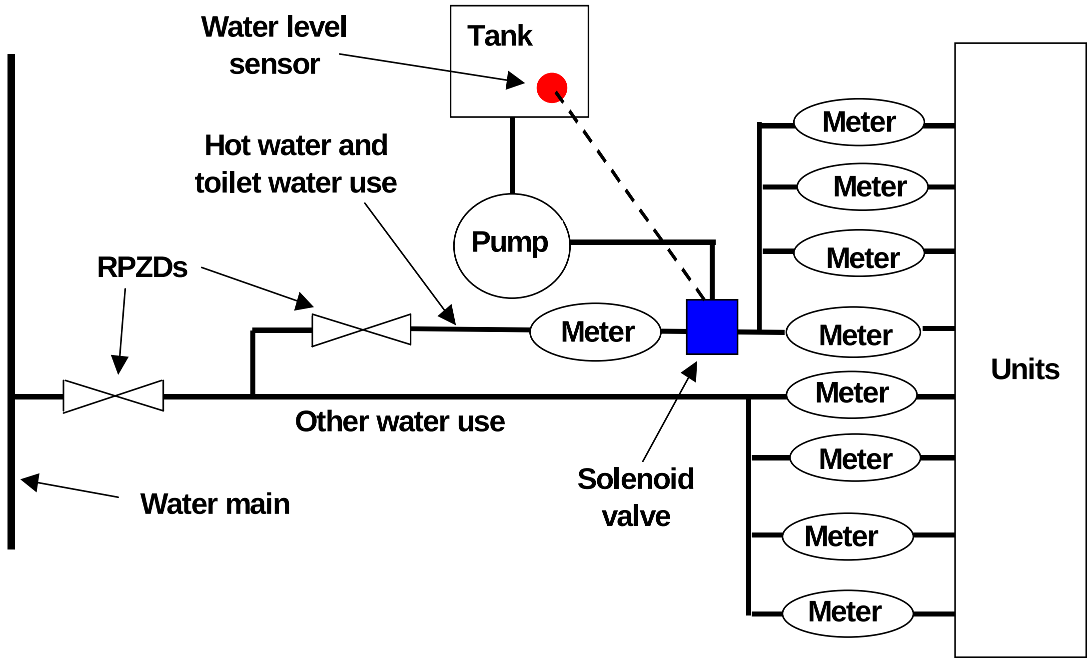

Figure 2.10: A schematic of the plumbing and metering system at Figtree Place

The operation of the rainwater supply system at Figtree Place was subject to many interruptions due to poor construction, reconstruction of elements of the system and intermittent failure of the solenoid valve arrangement. The performance of tank T2 in supplying rainwater to unit block D (Figure 2.1) was continuously monitored. Figure 2.11 shows the maximum tank water level and rainfall depth for each day from 27/04/99 until 14/08/00.

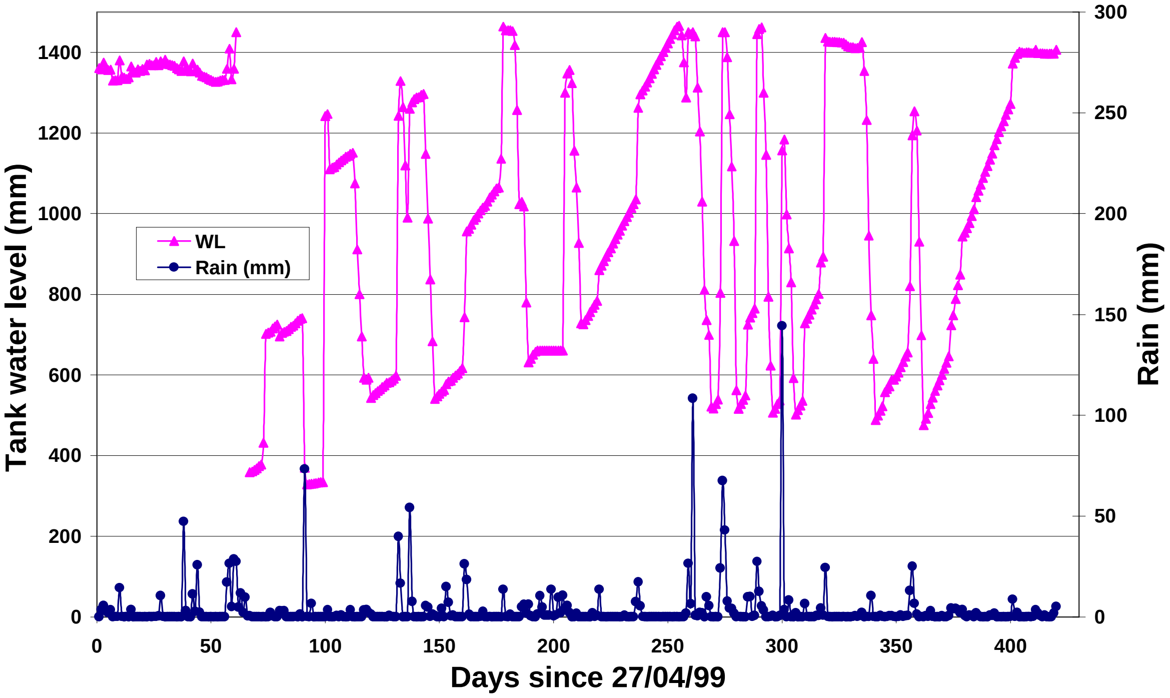

Figure 2.11: Daily water levels and rainfall at Figtree Place tank T2

Water levels in tank T2 are shown in Figure 2.11 to be constant on many days with no rainfall during the monitoring period. Unit block D consists of four units with a total of eleven occupants whose hot water and toilet water use was about 1050 Litres per day and the tank capacity was 8.9 m^3. Failure of the tank water level to be constantly drawn down indicated that the tank was often not in use. Water use from the tank was calculated using the monitoring results for rainfall and tank water level. Rainfall and tank water use were compared in Figure 2.12 in order to locate a period where the rainwater system was operating without interruption.

Analysis of Figure 2.12 indicates that the rainwater system at tank T2 was likely to be operating without interruption during the period from 2/03/00 to 14/04/00 (shown as day number 256 to 307 in Figure 2.12). Water balance calculations for that period indicated a 40% reduction in mains water use although meter readings for the same period showed a 33% reduction in mains water use.

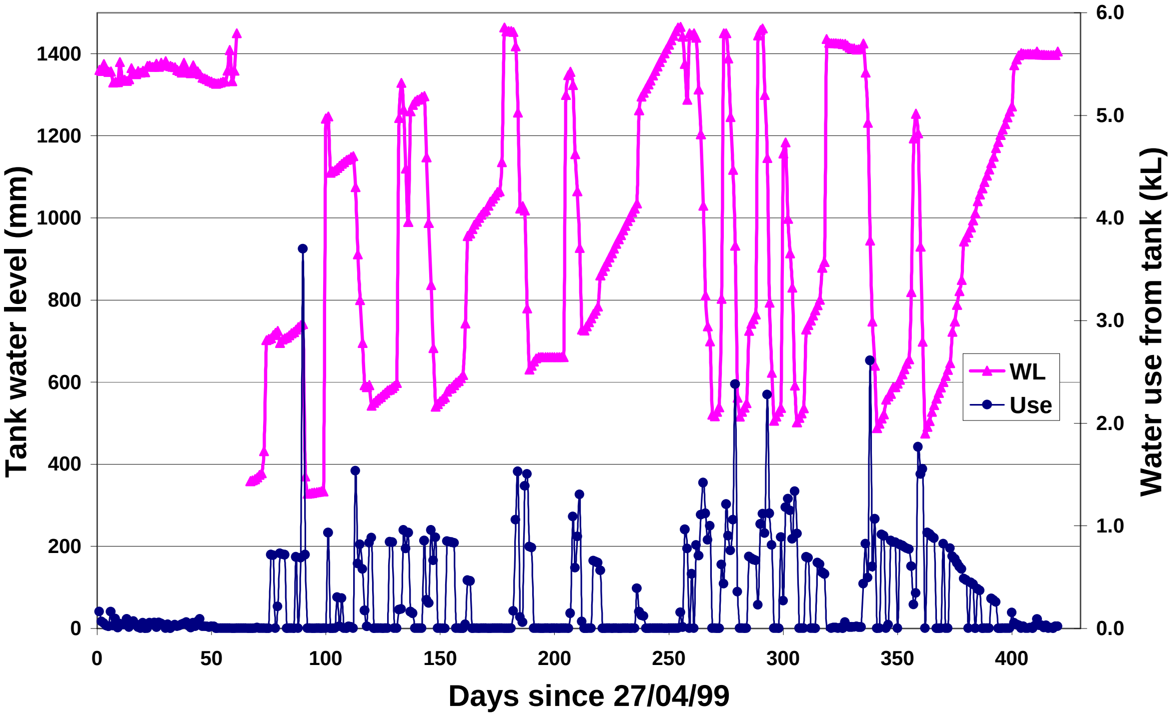

Figure 2.12: Daily water levels and water use from the Figtree Place tank T2

Analysis of the entire monitoring period from 8/09/99 to 14/04/00 using a water balance calculation revealed an 18% reduction in mains water use and meter readings showed a 13% reduction in mains water use. A consistent difference (5% - 7%) between water balance calculations and meter reading results for water use is noted. The HWC have established that household water meters underestimate water use by about 7% [B. Berghout, personal communication, 2001]. The difference between water use as estimated from meters and water balance calculations could result from errors at the meters. Small random errors in measurements recorded by the rain gauge and the pressure sensor in the rainwater tank could also influence the result.

The performance of the rainwater supply systems for each of the four unit clusters was calculated from meter readings for the period 2/03/00 to 14/04/00 and is shown in Table 2.12.

Table 2.12: Reduction in mains water use and statistics from all unit clusters for the period 2/03/00 to 14/04/00

Unit Cluster	Units	Occupants	Roof Area (m^2)	Tank Volume (m^3)	Reduction in Mains Water Use (%)
A	8	14	404	15.7	11
B	6	14	736	8.9	44
C	9	24	632	15.7	40
D	4	11	340	8.9	33

The results (Table 2.12) show that unit clusters B, C and D experienced a 33% to 44% reduction in mains water use whilst unit cluster A only showed an 11% reduction in mains water use. The significantly different performance of unit cluster A in comparison to unit clusters B, C and D results from the effectiveness of the first flush pits. Although, early in the project, the first flush pits were seen to separate the majority of roof water from entry to the rainwater tanks, only the pits at unit cluster D were reconstructed. The first flush pits at unit clusters B and C were partially reconstructed by reducing the diameter of the infiltration holes (Figure 2.3). The first flush pits at unit cluster A were not reconstructed resulting in the reduced water harvesting ability of the rainwater tank.

The operational and design statistics from the rainwater supply systems at unit clusters B, C and D are shown in Table 2.13. The tank volume per person, roof area per person and roof area for each cubic metre of tank volume are compared to the proportion of rainwater falling on each roof that is used in the units (shown as yield in Table 2.13).

Table 2.13: Operational and design statistics from unit clusters B, C and D for the period 2/03/00 to 14/04/00

Unit Cluster	Tank volume (m^3) per person	Roof Area /Tank volume (m^2/m^3)	Roof Area (m^2) per person	Rain (mm)	Roof Capture (kL)	Rain water Use (kL)	Yield (%)
B	0.635	83	53	386	284	43	15%
C	0.654	40	26	386	244	106	43%
D	0.809	38	31	386	131	27	21%

The rainwater supply system at unit cluster C with a 40% reduction in mains water use (Table 2.12) and a 43% utilisation of rainwater falling on the roof (shown as yield in Table 2.13) was the most efficient design. The configuration at unit cluster C includes a 0.654 m^3 rainwater tank volume and a 26 m^2 roof area per person, and 40 m^2 roof area per cubic metre of rainwater tank volume. Water use for unit cluster C was 257 Litres per person per day.

Unit cluster B had a similar rainwater tank volume per person (0.635 m^3/person) and reduction in mains water use (44%) to unit cluster C but had a significantly reduced yield (15%). The reduction in yield resulted from a greater proportion of roof area per person (53 m^2/person), a greater roof area per cubic metre of rainwater tank volume (83 m^2/m^3) and a lower daily demand (163 L/person/day). More rainwater is captured on a relatively larger roof area and transported to the rainwater tank. However, the tank has less storage available to accept the rainwater because lower daily demand results in tank water being drawn down less frequently.

The rainwater supply system at unit cluster D had the smallest reduction (excluding unit cluster A) in mains water use (33%) and a marginally higher utilisation of rainfall falling on the roof (21%) than unit cluster B. Unit cluster D has a similar roof area (31 m^2), a greater proportion of rainwater tank volume (0.809 m^3) and a lower water use per person (173 L) than unit cluster C.

The reduced utilisation of roof water at unit cluster D in comparison to unit cluster C is due to the lower daily water use at unit cluster D. The tank at unit cluster D had less storage space available to accept roof water due the lower demand.

Water levels in rainwater tanks used to supply domestic toilet flushing and hot water uses are constantly drawn down. This ensures that the tank regularly has storage capacity available to accept roof runoff resulting in reduced mains water use and stormwater discharge. The degree of reduced mains water use and roof water utilisation is dependent on the volume of rainwater tank storage, roof area and water use per person, and the proportion of roof area to rainwater tank volume.

Although analysis of the performance of the rainwater tank system at Figtree Place was obfuscated by intermittent operation of the system resulting from construction errors, ongoing reconstruction and a defective solenoid valve configuration reductions in mains water use of up to 44% was experienced. The utilisation of up to 43% of roof water also indicates that significant reductions in stormwater discharge are also possible.

It is important to note that the period of uninterrupted operation used for analysis was subject to an average of 9 mm/day of rainfall. This is a far greater rainfall than the 3.5 mm/day recorded during the entire monitoring period. Clearly the optimum combination of tank volume, roof area and water use per person, and proportion of roof area per cubic metre of tank volume will be different. Nonetheless, it is apparent that rainwater tanks can be designed to provide significant reductions in mains water use and stormwater discharge. The effective and uninterrupted operation of the rainwater supply scheme could reduce mains water consumption by 40% resulting in a mains water saving of the order of 1,644 kL per annum for the entire Figtree Place development. The performance of the rainwater reuse scheme is evaluated using a water balance model in Chapter 6.

2.8 Performance of the Infiltration and Groundwater Schemes

Stormwater management at Figtree Place is dependent on a central infiltration basin, rainwater tanks and infiltration trenches. Stormwater runoff from paved surfaces and lawns is directed to a central infiltration basin and overflow from the rainwater tanks is collected in infiltration trenches subsequently percolating to an unconfined aquifer (Figures 2.1 and 2.2).

Infiltration was the dominant natural process for predevelopment stormwater discharge at the sandy Figtree Place site. The soil profile consists of sand to a depth of ten metres overlying heavy clay with the aquifer about 2.5 m below the ground surface. To minimise the impact of infiltration practices upon aquifer levels groundwater was to be pumped from beneath the central infiltration basin for irrigation at Figtree Place and bus washing at the adjoining bus station. Nevertheless, the infiltration of stormwater to the aquifer evoked considerable concern from approval agencies [Argue, 1997], including:

- The potential for infiltration practices to produce increases in local groundwater levels that will adversely affect footings of the units and create unacceptable wet conditions in backyards and gardens.
- The possibility that infiltration practices will release undetected contaminants into the aquifer resulting in pollution of the Figtree Place irrigation supply and the supplies of downstream users.

- Infiltration measures including gravel filled trenches and dry basins will rapidly accumulate sediment during normal operation resulting in localised flooding and unacceptably long periods of ponding in the basins, backyards and gardens.

Industry concern about the performance of infiltration measures is largely based on the content of two reports from Maryland in the USA. Pensyl and Clement [1987] reported the performance of simple infiltration devices receiving roofwater and Lindsay et al. [1991] documented the performance of porous paving. Both reports document the performance of the infiltration measures over a six year period reporting failures in 40% - 85% of cases. Although these studies have created considerable uncertainty about the adoption of infiltration practices, Argue [1999] questions the validity of the reports given that they do not provide detailed information and have not been subject to informed industry debate. Indeed authors such as Allen and Argue [1992], Hopkins and Argue [1993] and Argue et al., [1998] describe the successful use of infiltration technologies. Was the infiltration strategy at Figtree Place successful? This section discusses the performance of the infiltration and groundwater schemes at Figtree Place. Monitoring results are presented in Appendix D.

2.8.1 The Infiltration Basin and Groundwater Levels

The irrigation and bus washing schemes using groundwater from the Figtree Place site were subject to intermittent operation. Similar to the rainwater use scheme, operation of the groundwater use scheme was limited by construction errors, reconstruction and interference. A HWC plumber frequently diverted the bus-washing scheme from groundwater to mains water supply. The performance of the infiltration basin and the aquifer levels were monitored to assess a “worst case” scenario where the majority of stormwater was infiltrated to the aquifer with very little groundwater used for bus washing or irrigation. The height of the water table (in mm above mean sea level) immediately below the infiltration basin is shown in Figure 2.13.

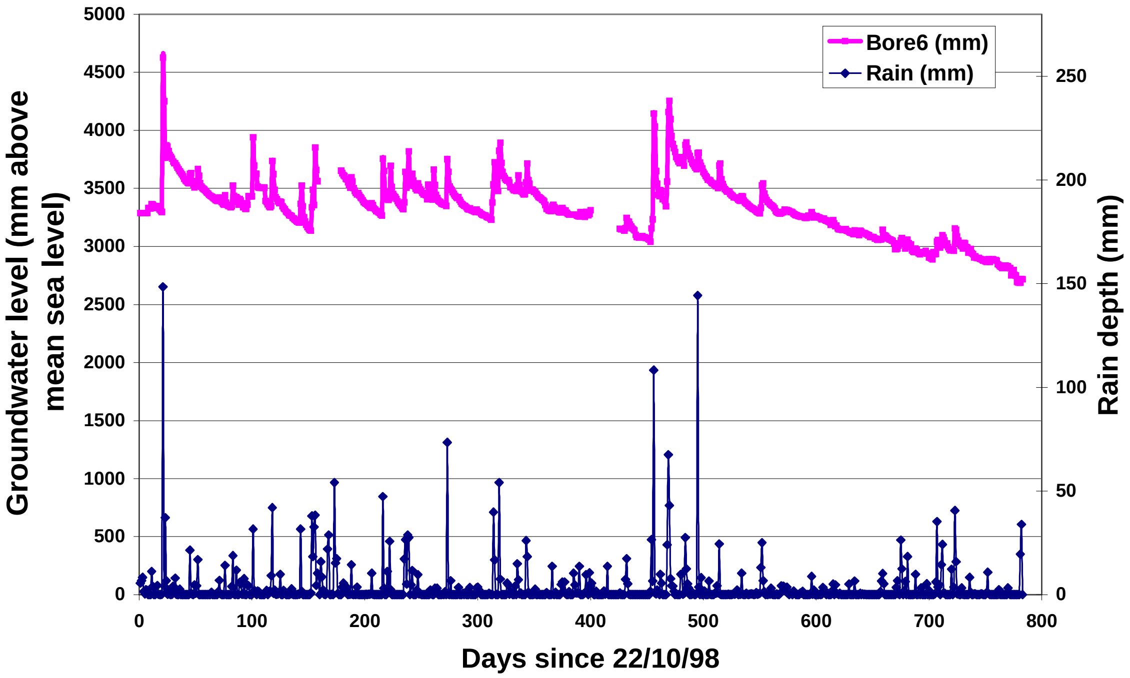

Figure 2.13: Height of the water table below the central infiltration basin

Figure 2.13 reveals that the groundwater levels (shown as Bore 6 in Figure 2.13) varied with rainfall depth during the life of the project. This is highlighted by the steady decline in groundwater level in response to a decreased rainfall depth after day number 500. The results also show that the groundwater level did not approach the ground surface level at the invert of the infiltration basin (6000 mm) during the monitoring period suggesting that no unacceptably wet conditions were created in backyards or gardens and unit footings were not adversely affected. In fact on only one occasion did the water table come within 1.5 m of the ground surface in the infiltration basin.

The groundwater levels immediately under the infiltration basin (Bore 6) shown in Figure 2.13 do not discriminate between the regional and local response of groundwater levels to rainfall depth. In order to determine the effect of the infiltration measures on the aquifer below Figtree Place the groundwater levels at a number of bores (Bores 1 – 6 shown as B1 – B6 in Figure 2.1) are shown in Figure 2.14.

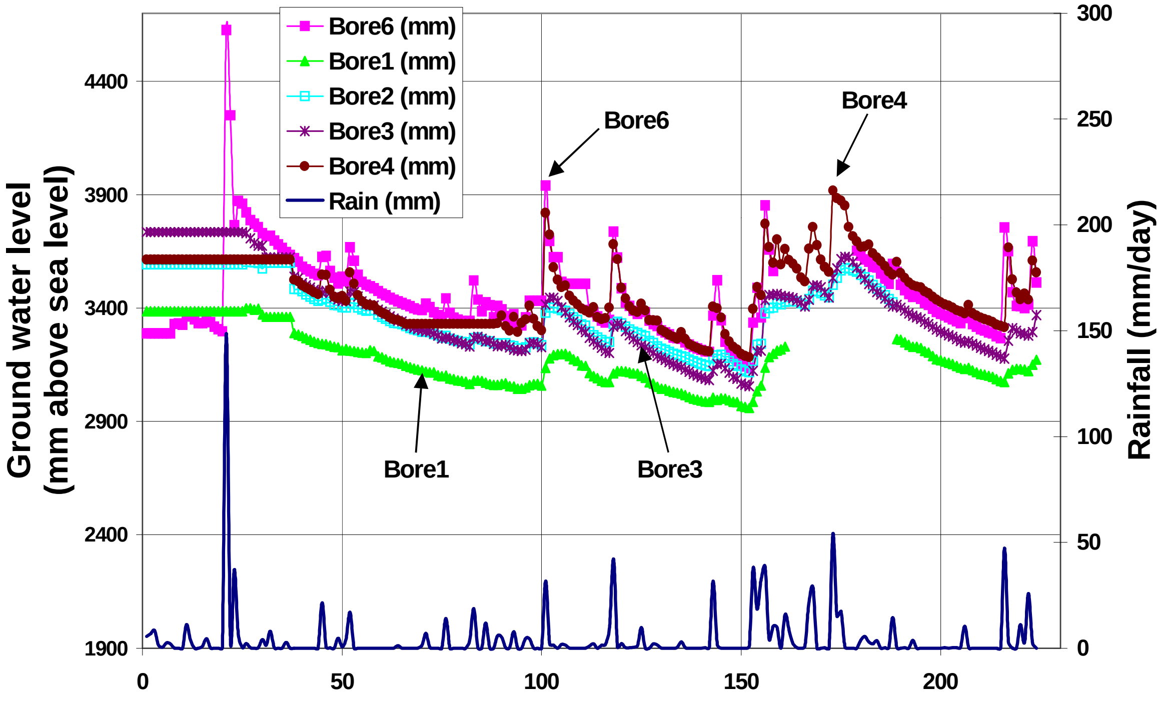

Figure 2.14: Height of water table at all bores

Figure 2.14 shows the relative response of the groundwater levels below Figtree Place as recorded by Bores 1 to 6. The groundwater beneath the site is part of a large unconfined aquifer that moves slowly (about 4 m per year) [Argue, 1997] from Bore 3 to Bore 1. Bore 3 provides the upstream groundwater level and Bore 1 provides the downstream groundwater level. The groundwater levels at Bores 4 and 6 should be between the levels from Bores 1 and 3 because Bores 4 and 6 are between Bores 1 and 3 and are affected by recharge from the infiltration basin. The groundwater levels at Bores 4 and 6 are higher than Bores 1 and 3 (Figure 2.14) indicating that the infiltration scheme has created a localised increase in groundwater levels. The groundwater levels have increased by an average 250 mm above the expected normal position of the water table.

The response of groundwater levels at Bore 6 below the infiltration basin and Bore 4 adjacent to an infiltration trench to rainfall depth is also more dramatic than the surrounding groundwater levels (Bores 1, 2 and 3). The groundwater levels below the infiltration trenches and basin are seen to increase rapidly during rain events and dissipate quickly following rain events. The rapid response of the local groundwater levels to rainfall is due to the high vertical hydraulic conductivity of the sandy soils at the site. The vertical hydraulic conductivity was reported to be 0.162 m/hour by Argue [1997].

The performance of infiltration basins can be assessed by examining the depth of ponding, emptying time and infiltration rates over a long period [Argue et al., 1998]. The performance of the central infiltration basin is shown in Figure 2.15.

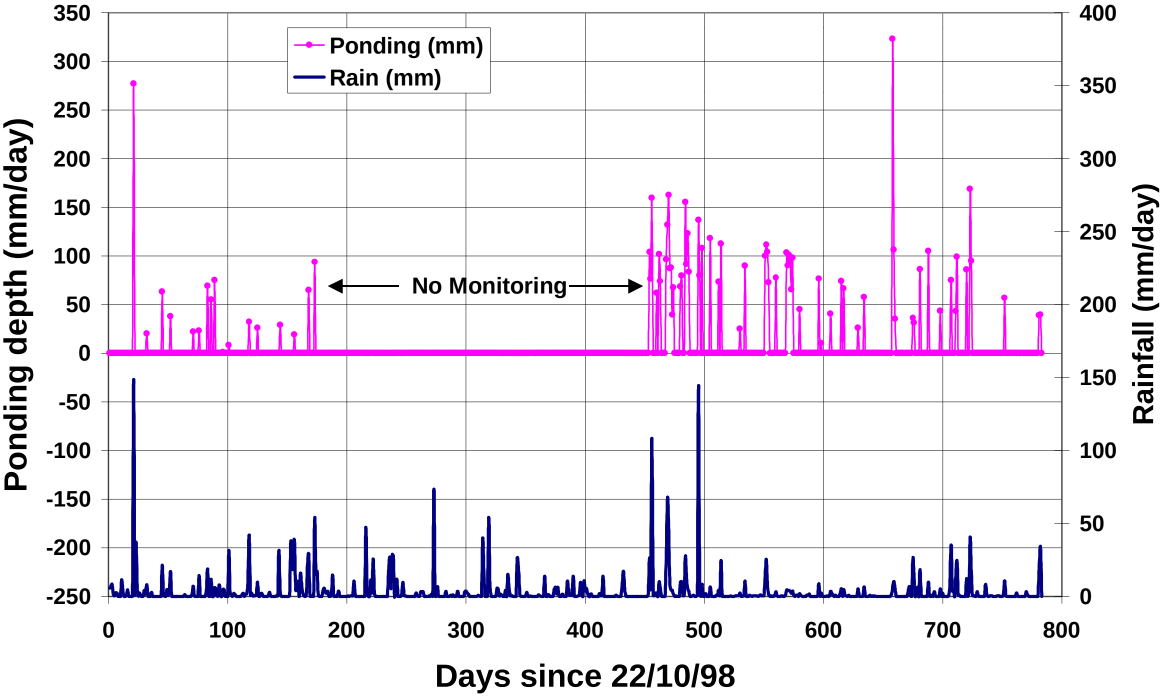

Figure 2.15: Depth of ponding in the central infiltration basin and daily rainfall

Figure 2.15 shows the depth of ponding in the infiltration basin and the corresponding rainfall depth on each day during the monitoring period. Monitoring of ponding depth in the infiltration basin was interrupted by construction activities between the days numbered 174 and 454 (Figure 2.15). During the construction period heavy machinery and materials were stored in the infiltration basin. Stormwater overflow from tank T2 was redirected to the infiltration basin. This is shown in Figure 2.15 to increase ponding depths in the basin after day number 454.

It is commonly believed that the materials in infiltration areas subject to vehicle traffic or other weights will compact leading to the failure of the basin [F. Cosgrove, Newcastle City Council, personal communication, 1999, Argue, 1999 and Todorovic et al., 1999]. Failure of the basin can be indicated by an unacceptably long emptying time. After completion of the construction activities, monitoring of ponding levels in the basin was continued to assess the impact of construction practices on the performance of the basin. The minimum, maximum and average values for ponding depth, rain depth, infiltration rates and emptying time are shown in Table 2.14.

Table 2.14: Performance statistics from the infiltration basin for the entire monitoring period (23/10/98 to 1/12/01)

Category	Minimum	Maximum	Average
Ponding depth (mm)	1	332	76.9
Rain depth (mm)	1.43	148.51	18.63
Infiltration rate (m/hr)	0.07	1.34	0.394
Emptying time (hrs)	0.002	19.68	3.31

The maximum infiltration rate is shown to vary from a minimum of 0.07 m/hr to a maximum of 1.34 m/hr with an average of 0.394 m/hr. The average infiltration rate measured at the infiltration basin is considerably larger than the test results reported in Argue [1997] (0.162 m/hr). The greater infiltration rates are due to the modified soil conditions in the infiltration basin. The replacement of the sandy soil with a layer of gravel and the depth of ponding allowed by the basin will increase infiltration rates.

The average emptying time for the basin of 3.31 hrs (Table 2.14) is considerably less than the emptying time of 24 hrs determined by Argue [1998] to indicate acceptable performance of infiltration basins. Indeed the observed maximum emptying time (19.68 hours) is less the recommended emptying time indicating than the performance of the basin has been acceptable.

The average depth of ponding in the infiltration basin was 76.9 mm (Table 2.14) and the maximum ponding depth was 332 mm. The central infiltration basin is designed to overflow to the adjoining internal road at a depth of 350 mm. At a depth of 600 mm stormwater from the combined central infiltration basin and internal road system discharges to the street drainage system. The surrounding buildings would be inundated by stormwater if the ponding depth reached 750 mm. Manual and automated observations during the monitoring period show that basin did not overflow onto the adjoining internal road. Significantly, no stormwater has discharged to the street drainage system during the life of the Figtree Place project. Figure 2.16 shows the ponding depth, rainfall depth and aquifer levels during the largest storm recorded during the monitoring period.

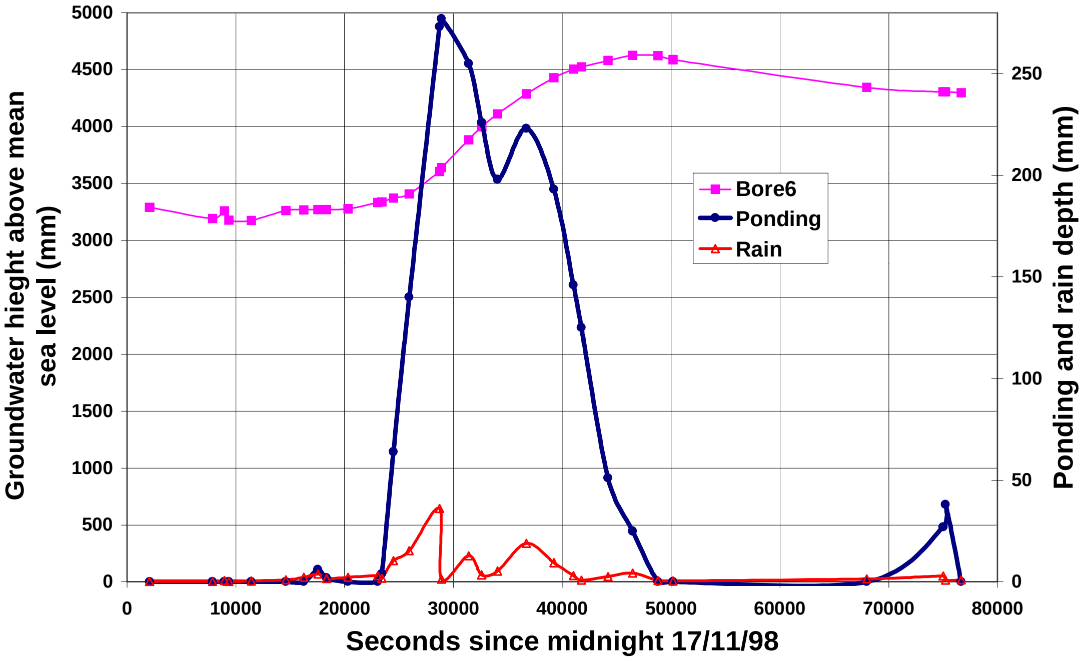

Figure 2.16: Performance of the infiltration basin during a storm event on the 18/11/98

Figure 2.16 shows that the ponding depth increased during the rain event and dissipated soon after the event ceased. The height of the water table (Bore 6) below the basin is seen to increase steadily during the rainfall event. A maximum groundwater level is reached soon after the infiltration basin empties and groundwater levels steadily decrease throughout the remainder of the day. Stormwater collected in the infiltration basin percolates rapidly through the gravel base of the basin to the aquifer creating a localised increase in groundwater level. The steady decrease in groundwater level following emptying of the basin suggests that infiltration is causing localised increases in groundwater movement.

Monitoring of ponding in the infiltration basin commenced immediately following the end of construction activities on the 22/10/98 and ceased due to reconstruction efforts during the period 23/06/99 until 6/03/00. An average infiltration rate of 0.485 m/hr was observed at the central infiltration basin during the period prior to reconstruction. The observed ponding depths in the basin were used to determine the infiltration rates.

The monitoring of ponding in the infiltration basin commenced immediately following the end of reconstruction activities on the 6/03/00 and continued until the 1/12/01. An average infiltration rate of 0.36 m/hr was observed during this period.

The results suggest that the performance of the infiltration basin was compromised by the reconstruction activities. The average infiltration rate prior to the reconstruction period (0.485 m/hr) was found to be higher than the average infiltration rate (0.36 m/hr) measured following the period.

2.8.2 Groundwater Quality

Prior to construction of the Figtree Place development the EPA expressed concern that stormwater percolating through infiltration devices and soil potentially contaminated with petroleum products could mobilise contaminants from the soil to the aquifer. The DLWC and the PHU were also concerned that the groundwater would be unsuitable for irrigation because it may be saline or pose a health risk to residents. The management of the adjoining bus station was concerned that the use of groundwater with a high iron content for bus washing might stain the paintwork on the buses.

Immediately following the commencement of the research program groundwater samples were taken from the groundwater supply bore (Bore 6) below the central infiltration basin. The samples were tested for the presence of Petroleum Hydrocarbons, Benzene, Toluene, Ethyl Benzene and Total Xylene. These contaminants were not detected. Samples were taken at the same location on five occasions through out the research program. The results for physical and chemical parameters are shown in Table 2.15.

Table 2.15: Groundwater quality results

Parameter	Unit	Average	Maximum	Minimum	Guideline
Sodium	mg/L	13.22	28.20	<0.01	180
Calcium	mg/L	5.24	7.90	1.10	200
pH		5.55	7.40	4.40	6.5 - 8.5
Dissolved solids	mg/L	168.00	255.00	59.00	500
Suspended solids	mg/L	0.72	1.10	0.20	500
Chloride	mg/L	21.60	26.10	14.70	250
Nitrate	mg/L	<0.05	<0.05	<0.05	3
Nitrite	mg/L	0.56	1.20	0.10	50
Sulphate	mg/L	40.60	52.40	18.30	250
Ammonia	mg/L	0.37	0.80	0.08	0.5
Lead	mg/L	<0.01	<0.01	<0.01	0.01
Iron	mg/L	0.14	0.18	0.10	0.3
Zinc	mg/L	0.08	0.12	<0.05	3
Cadmium	mg/L	<0.002	<0.002	<0.002	0.002

The results in Table 2.15 show that groundwater complied with the Australian Drinking Water Guidelines for the physical and chemical parameters tested with the exception of the parameter pH. The values for parameter pH were found to vary from 4.4 to 7.4. The average value of 5.55 is below the recommended guideline value of 6.5. This indicates that the groundwater is slightly acidic and may be corrosive to plumbing fittings or pipes [NHMRC, 1996]. The corrosive effect of the water will depend on the concentration and types of ions in the solution, the availability of Oxygen, water temperature and the material that the water is in contact with.

The groundwater was acceptable for irrigation purposes due to its low salinity indicated by the concentrations of Dissolved Solids, Calcium and Sodium. It also appeared to be acceptable for bus washing purposes with low levels of Iron detected. The groundwater was used intermittently (interrupted by construction errors and so on) for bus washing and irrigation throughout the project.

2.8.3 Ground Water Use

During August 1999 groundwater from Figtree Place was first used for bus washing in the adjoining bus station immediately following the construction of an improved design (by the author) for the storage tank used for bus washing. On the first day of operation 4.7 kL of groundwater was used for bus washing. During August a total of 64 kL of groundwater was used for bus washing although only 347 kL of groundwater was used for bus washing up to

October 1999. No groundwater reuse for bus washing was recorded during or after October 1999.

Unfortunately the reuse of groundwater for bus washing was intermittent due to reconstruction activities and strong disapproval by a HWC plumber. The HWC plumber believed that reuse of groundwater for bus washing was dangerous creating an unacceptable risk of cross connection between groundwater and mains water at the bus washing storage tank [N. Roser, Newcastle City Council, personal communication, 1999]. The storage tank was topped up with mains water or groundwater to supply the washing mechanism. A plumber was commissioned to connect the groundwater supply directly to the storage tank and install an air gap backflow prevention method in accordance with Australian Standard AS/NZ 3500.1.2 Water Supply: Acceptable Solutions [AS/NZ 3500.1.2, 1998]. The solution developed in accordance with ASNZ 3500.1.2 is shown in Figure 2.19.

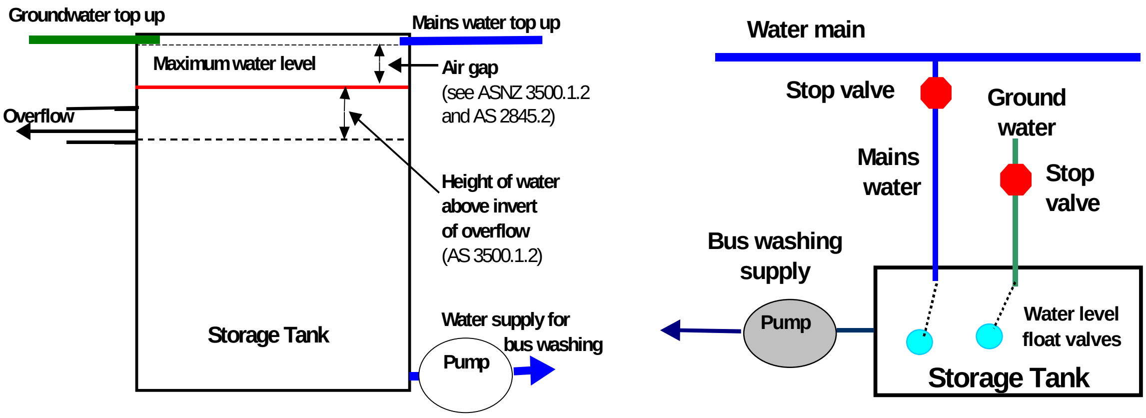

Figure 2.19: Configuration of the mains water and groundwater top up of the bus washing storage tank.

The preferred water supply for the storage tank (Figure 2.19) can be chosen by opening (or closing) the stop valves on the mains water and ground water supply pipes. The water level in the storage tank is maintained at the invert level of the overflow pipe by float valves on the groundwater and mains water supply pipes and a large diameter overflow pipe. When the water level reaches the desired height the float valves closes both the groundwater and mains water pipes with any excess water discharged via the overflow pipe.

The design provides three independent methods for prevention of cross connection between groundwater and mains water. Either of the stop valves can be closed to eliminate the possibility cross connection, closure of the supply pipes by the float valves prevents stored water reaching or entering the pipes and the use of a large diameter overflow pipe provides an air gap ensuring that the stored water does not reach or enter the supply pipes. The provision of an air gap for backflow prevention is reported in AS/NZ 3500.1.2 as acceptable for low to high hazard rated cross connections. However the HWC plumber's disapproval of the groundwater reuse system continued resulting in infrequent utilisation of the scheme.

The groundwater reuse schemes for bus washing and irrigation with uninterrupted operation could provide considerable reduction in mains water use. The bus washing scheme could reduce mains water use by 1,800 kL/yr. No meters were provided to measure the volume of groundwater reuse for irrigation. Hence the volume of groundwater used for irrigation is unknown although Argue [1997] estimated irrigation water use to be 300 kL/yr. The groundwater reuse scheme could reduce mains water use by up to 2,100 kL/yr.

2.9 Comparative Costs

The construction costs of traditional and WSUD practices are compared for the Figtree Place project to determine the economic benefit of the WSUD scheme. In the approximate economic analysis presented below costs are based on the existing system and benefits are calculated from the expected uninterrupted performance of the development. The costs of the conventional stormwater system have been derived from a design that complied with Newcastle City Council's Development Control Plan 50: Stormwater Management for Development Sites. Details of the calculations are provided in Appendix E. Experience has pointed to improved designs that are less expensive. These improved designs are addressed in Section 3.1.

Basic project costs are as follows:

development cost (27 units, etc.) :	$2,700,000
'water-sensitive' design elements (rainwater tanks, pumps, recharge basin and plumbing):	$62,400

alternative conventional stormwater system elements as required by DCP 50 [NCC 1999]:	$88,300

Hence, the ‘water-sensitive’ elements of the design represent a **saving,** when compared with conventional practice, of $25,900 or 1% of development cost. McAlister [1998] found a similar result demonstrating that a WSUD subdivision in Brisbane was expected to have capital costs, allotment yield and marketable values similar to that of a traditional design. The estimated annual water saving for Figtree Place and the adjacent Bus Station is calculated as follows:

total water saving (residences) :	1,644 kL / annum
irrigation saving:	300 kL / annum
bus-washing saving:	1,800 kL / annum
HWC charges per kL of mains water:	$0.92
hence, expected overall savings :	**$3,444 per annum.**

Assuming that the construction savings of $25,900 are invested for a ten year period at an interest rate of 6% the annual value of the construction savings is $3,478. The approximate annual value of the cost saving at Figtree Place is therefore:

Water savings:	$3,444
Annual investment saving:	$3,478
Less annual depreciation and maintenance costs (estimated to be 2% of WSUD construction costs):	$1,248
Total annual saving:	**$5,674**

If policies are adopted to encourage WSUD and many such projects are completed, then substantial urban infrastructure cost savings to the community are likely to materialise. If an agency responsible for local water supply and stormwater runoff control has reached the stage of full utilisation of its infrastructure and is faced with the decision to expand its headworks and water distribution system and stormwater infrastructure to meet the needs of extra population, then a **comparison** should be made between:

- the lifecycle cost of **new and existing infrastructure** required to satisfy the (conventional) additional water supply demand and stormwater load, and,

- the lifecycle cost of **new practices** which decrease water consumption and stormwater load and hence defer the need for new infrastructure

A comparative analysis of economic externalities such as environmental and social consequences of traditional and WSUD systems is also very important. A full exploration of comparative economics is possible using Figtree Place as an example of ‘new practices’. Detailed analysis of opportunity cost savings of delayed augmentation of infrastructure resulting from implementation of rainwater tanks is undertaken in Chapter 10.

The cost savings to the community from such implementation are perceived to be significantly greater than the site benefits estimated in this Chapter. Andoh and Declerck [1999] found that retention and infiltration measures used as source controls reduced infrastructure maintenance and rehabilitation costs for combined sewerage systems by 30% to 80% compared to traditional practices and also significantly reduced pollution of receiving waters.

2.10 Summary

Much has been learnt about the design, management and maintenance of the Figtree Place demonstration project. A greater understanding of the design requirements and discovery of many construction/design shortcomings has enabled redesign and reconstruction of elements of the development. This has resulted in improved knowledge of the construction costs and design issues applicable to other projects. In the author’s view this is the principal benefit of the Figtree Place experiment.

This Chapter summarises the results from the Figtree Place experiment. Although experience has revealed significant flaws in the construction/design of the project resulting in the intermittent operation of the rainwater and groundwater reuse schemes much has been learnt from ‘worst case scenario’ monitoring and analysis. Some important conclusions that support implementation of WSUD source control measures are provided:

- Hot water (storage) systems supplied with rainwater contaminated with bacteria, can deliver water meeting Australian Drinking Water Guidelines provided that they are operated at temperatures in the range 50°C and 65°C: hot water quality is related to use, capacity and temperature setting;

- Although the quality of rainwater collected from roofs occasionally exceeded the guideline values for ammonia, pH, iron and lead, samples of rainwater from tanks and hot water systems was found compliant with chemical and metals parameters in the Australian Drinking Water Guidelines.
- The quality of rainwater is improved by storage in tanks. The water treatment processes of flocculation, settlement and bio-reaction appear to operate in rainwater tanks to improve water quality.
- The combination of the rainwater tank and hot water system is an effective water treatment process that produces water quality results compliant with drinking water guidelines.
- Responses to a questionnaire from a small sample (n=26) indicate Figtree Place resident approval of the use of stormwater runoff for outdoor purposes, and the use of rainwater for outdoor, toilet, hot water and laundry purposes.
- The use of roof water collected in rainwater tanks for hot water systems and toilet flushing is expected to yield residence **internal** water savings of up to 44%.
- There has been no stormwater runoff from Figtree Place to the street drainage system. The combination of rainwater tanks, infiltration trenches and basin proved a successful stormwater management strategy.
- The Figtree Place demonstration project produced small total annual cost savings when compared with traditional stormwater and water supply practices. Likewise the WSUD elements provided small construction cost savings over traditional stormwater practices.
- The existing design details in the Figtree Place demonstration project can be further improved with consequent lower costs.

Operation of the Figtree Place demonstration project has revealed opportunities for improved design in the form of reduced plumbing, exclusion of redundant elements and more efficient construction practices. The Figtree Place experiment provides evidence that the use of rainwater tanks will reduce mains water consumption, stormwater discharges and construction costs although the magnitude of these benefits is uncertain due to flaws in the construction of the project. An existing housing allotment in Maryville, a suburb of Newcastle, Australia has been fitted with a rainwater tank to investigate costs and performance of improved design practices that have resulted from the Figtree Place experience. The performance of the Maryville house is discussed in Chapter 3.