Figtree Place: A Case Study in Water Sensitive Urban Development (WSUD)

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Abstract

Figtree Place is a water sensitive urban redevelopment consisting of 27 residential units located in Hamilton, an inner suburb of Newcastle, NSW, Australia. The site uses rainwater tanks, infiltration trenches and a central basin where cleansed stormwater enters the unconfined aquifer for water retention and retrieval. A two-year monitoring program for roofwater, raintanks, hot water systems and first flush pits has commenced with samples taken from these sources tested for compliance with the Australian Drinking Water Guidelines (1996). Total water saving of around 60% has been shown to be feasible as well as almost complete storm runoff retention.

Keywords

Economics, infiltration, recharge, residential, re-use, stormwater, water conservation, water quality.

Introduction

The maxim “Think globally, act locally” is usually understood to refer to worldwide environmental values being achieved through positive, affordable action taken by local communities. This fusion of ecologically sound practice with economic viability is central to the concept of sustainable development (WCED, 1990). A microcosmic interpretation of the maxim can be that “global” refers to city infrastructure and “local” may be identified with individual dwellings or commercial/public buildings or groups of such buildings that, collectively, comprise the city.

While this interpretation of “global” may be used to develop practices which are ecologically sustainable in the full range of utilities found in a metropolis (transport, power, sewerage, and gas) the focus of this article is on the services which provide water and the disposal of stormwater. Water sensitive urban development (WSUD) is a local solution to the global problems created by reliance on conveyance and centralised storage/discharge of water in cities.

Developments which are “water-sensitive” involve water conservation and stormwater retention strategies employed at the urban allotment or “cluster” level to reduce infrastructure costs and environmental degradation of aquatic environments. The principles of the WSUD approach have been incorporated into a demonstration project in Newcastle, New South Wales, Australia. Newcastle is a major Australian coastal city 160 km north of Sydney. With a population of 140,000 plus 350,000 people living in the surrounding region, Newcastle is the largest urban concentration in Australia after the five mainland capital cities.

In August 1995 Newcastle City Council adopted its “Environment Management Plan: A vision for a clean and healthy city”. This plan built on some important initiatives already underway in Newcastle, funded by the Australian Government’s “Building Better Cities” program. The demonstration project described in this paper resulted from collaboration between the two Agencies and NSW Department of Housing and relates to redevelopment of a 0.6ha portion of the Hamilton Bus Station site (3.0 ha area) called “Figtree Place” in central Newcastle. The redevelopment involved the construction of 27 housing units. This study reports early and significant findings that have emerged from the two-years monitoring programme.

The Site And Its Capabilities

Previous occupation of the Figtree Place site as Newcastle's main public transport hub went back to the early 1900s with initial use by trams and more recently buses. Over the years serious spillage of hydrocarbons had occurred leaving the deep-sand site (sand depth: 10 m) in a highly contaminated state with "hot spots" of PAH, TPH, heavy metals, pesticides and oil and grease. Concrete "capping" was used as a remedial action and the area subsequently used for bus parking.

Geotechnical testing at the site showed that the contamination was confined to a layer 300 mm deep below the "cap". At greater depth (3-4 metres), groundwater of a quality satisfactory for irrigation was found. The first action in proceeding with the Figtree Place demonstration project involved removing the concrete "cap" and the upper 300 mm of soil and replacing this with clean sand fill. Every effort was made to decontaminate, to whatever depth necessary, pollutants found in "hot spot" concentrations. Despite this, the possibility remained that rainfall on the site as well as the action of stormwater retention facilities such as proposed "soakaways" might cause undetected contamination to be mobilised and conveyed to the aquifer.

A Concept Study undertaken by the Urban Water Resources Centre for Newcastle City Council (Argue, 1997; Argue and Argue, 1998) showed that stormwater available from all potential sources, assuming high levels of retention and recharge of groundwater, could make a major contribution to domestic uses. The domestic uses examined included hot water, toilet flushing and open space irrigation but excluded drinking water. Drinking water was excluded from the study on health grounds rather than inadequate resources. A significant over supply of water was realised and an approach made to the adjacent Bus Station management to join a collaborative venture using the excess clean water for bus washing.

With agreement reached "in principle" on the latter issue, detailed planning of the proposed development was able to proceed with confidence that sufficient water could be harvested on site to meet:

- 50% in-house needs for hot water and toilet flushing
- 100% domestic irrigation needs
- 100% bus-washing demand.

An added advantage of the stormwater harvesting proposal was the retention of a large portion of the stormwater runoff. This added value to the project by reducing the downstream flood peak , thereby reducing strain on the stormwater infrastructure, including pollution control installations.

Approval Agencies: Reactions and Requirements

There were five main areas of concern for approval agencies represented on the project Steering Committee:

- the potential for undetected contaminants being released into the groundwater;
- the possibility that water retention practices might produce a groundwater "mound" that would compromise the structural integrity of buildings;
- the potential for health problems as a result of unsanitary water, collected from roofs and used in hot water systems, being ingested;
- the potential for a repeat of drought conditions, such as experienced in 1993 and 1994, causing serious disruption to in-house supplies;
- the possibility of extreme rainfall causing severe flooding of residential units on the site.

In addition to these concerns were a set of questions for which answers were eagerly sought by utilities' representatives :

- will the development be cost-effective at the level of the individual householder and/or for agencies responsible for urban infrastructure?;
- what maintenance is required on a regular and long-term basis? What is its cost?;

- what in-house water savings are possible using rainwater tanks for part of toilet flushing and hot water supply?;
- what out-door water savings are possible using on-site retention with aquifer storage/recovery?;
- what reduction in drainage infrastructure is possible with a high level of stormwater retention on site?

Layout and Main Features

The plan of Figtree Place is shown in Figure 1.Its main features are :

- 27 home sites :

single bedroom residences:	3
two bedrooms residences:	18
three bedrooms residences:	6

  The effective housing density is 45 units per ha;
- underground rainwater tanks fitted with "first flush" diversion devices; between four and eight houses per rainwater tank;
- gravel-filled trenches at front or rear of 19 home sites : trenches receive rainwater tank overflow and provide recharge to groundwater;
- all runoff from paved area (including carriageway and driveways) in front of 19 homes gathered and diverted to central Detention Basin Recharge Area; recharge of cleansed stormwater to groundwater;
- design flood capacity (before overflow to Denison Street, north boundary) : "once in 50 years";
- paved area surface runoff from seven units in north-east corner uses conventional street drainage system; roof runoff from these units collected in a rainwater tank.
- ground water from a bore located in the recharge area provides water for irrigation and bus washing at the adjacent Bus Station

A schematic representation of the water sensitive features of Figtree Place is presented in Figure 2. Rainwater collected from roofs flows via stormwater pipes through a "first-flush" pit into each rainwater storage tank. Pumps with pressure cells supply rainwater from tanks for use in storage hot water systems and for toilet flushing. If a raintank's capacity is exceeded, overflow is directed to a gravel trench which supplies recharge to the unconfined aquifer. Coombes et al. (1999) provide further design details for the site.

Stormwater runoff from paths, lawns and gardens is directed into the Detention Basin via internal roadways (see Figures 1 and 2). The Detention Basin recharges the unconfined aquifer and provides an open space recreation area during dry spells. The Detention Basin has been sized to contain, without overflow, all storms up to and including the "once in 50 years" event.

Reinforced concrete underground rainwater tanks are used at Figtree Place. The "first flush" pit associated with each of these tanks is designed to separate the first 2mm of rainfall from the inflow. The four rainwater tanks are rectangular with capacities ranging from 9 kL to 15 kL. Each raintank contains 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 a pipe conveying overflow to a recharge trench. The low water level monitor activates a system which enables water to be drawn from mains supply whenever the water level in the tank is low.

Recharge trenches were constructed as 750mm deep x 1000mm wide gravel "sausages" enclosed in geofabric covered by 300mm depth of topsoil. Overflow from raintanks is conveyed to the recharge trenches via PVC pipes and distributed within the trenches by slotted pipes.

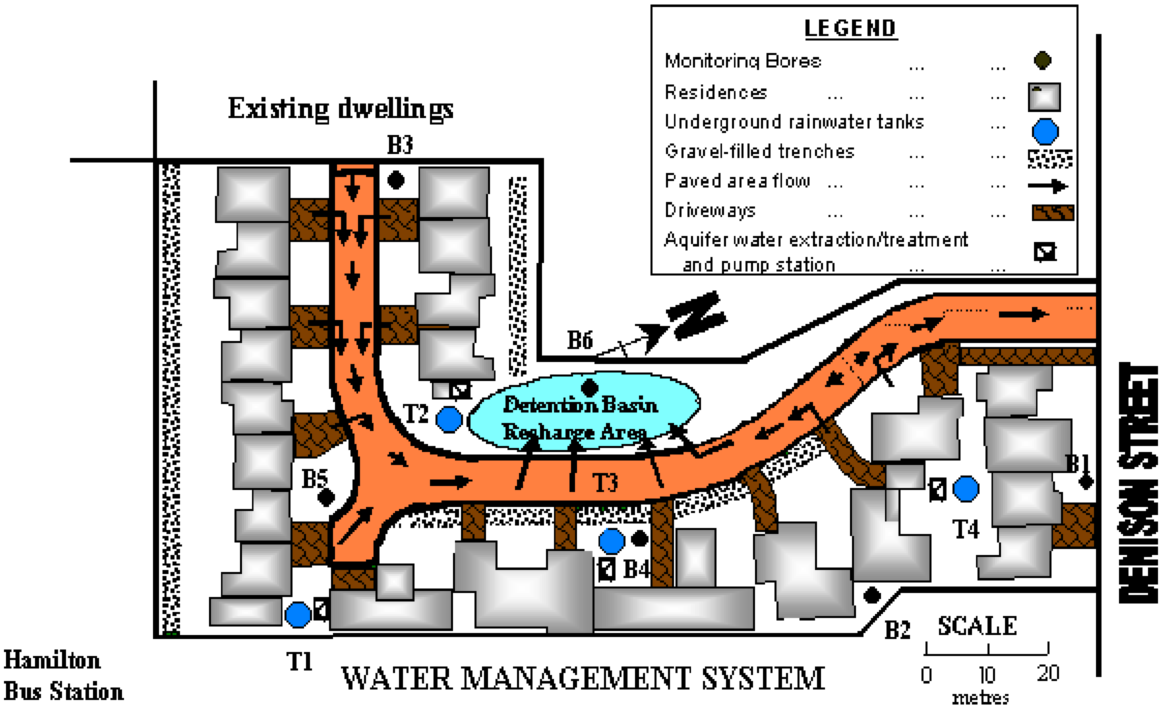

Figure 1: General plan and water sensitive design elements of Figtree Place

The Detention Basin is a grassed depression with an area of 250m^2 that overlays a 750mm layer of gravel enclosed in geofabric. A submerged pump supplying groundwater for irrigation and bus washing is situated within the Basin at a depth of 10 m.

Pumps with pressure vessels are situated in pump houses adjacent each raintank shown in Figure 1. Each pump house has a number of fail-safe 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, or electricity supply is interrupted or if a low water level is detected in a raintank.

Monitoring Details

A comprehensive monitoring program (manual and automated) is being conducted to assess water quality, water use, social acceptance of water-sensitive design elements, maintenance issues and economic performance (Coombes et al., 1999). The manual sampling program accesses water quality of roof runoff, “first-flush” pits, raintanks and hot water systems on a monthly basis. Table 1 lists the currently monitored bacterial and chemical parameters: guideline values taken from the Australian Drinking Water Guidelines (1996) are also listed.

Accumulating and tipping-bucket raingauges paired at two sites measure rainfall. Roof water is collected on an event basis from roofs using 50L plastic containers connected to downpipes. A refrigerated water quality sampler is used to sample roof water at its entry into a “first-flush” pit. The water quality data from the refrigerated sampler are used to verify the event-based sampling results and also to study the variation of roof water quality within each storm event.

An automated monitoring site was established at the pump house adjacent to the western tank (T2) shown in Figure 1. The site includes a data logger, tipping bucket rain gauge, pressure sensors, a water quality monitor and a refrigerated water quality sampler. The data logger controls all monitoring and recording processes.

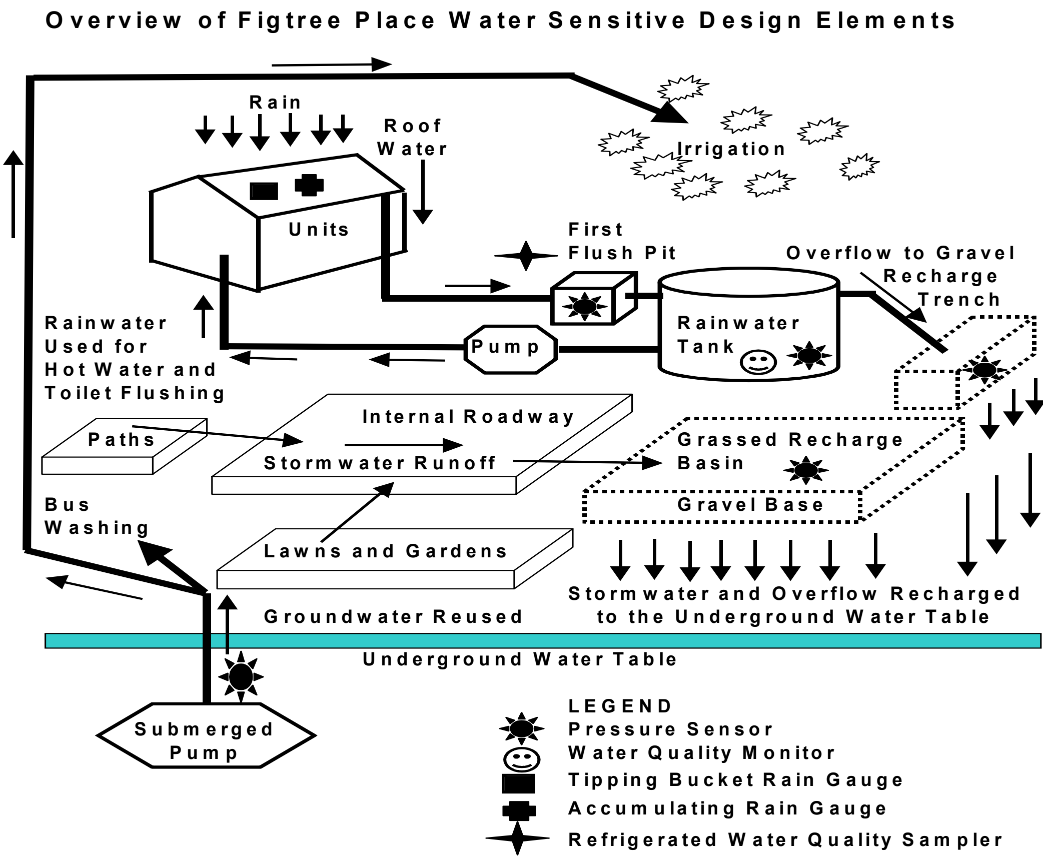

Figure 2: The Figtree Place Water Sensitive Design Concept

Pressure sensors are used to measure water levels in the "first-flush" pit, in raintanks, and in groundwater bores (B1 to B6 in Figure 1). Pressure sensors are also placed in a small pit with a grate cover in the recharge basin to measure ponding depth, and in a slotted pipe standing upright within the gravel layer in the recharge trench to measure recession behaviour. The water quality monitor measures temperature, pH, DO, conductivity, turbidity and salinity of water stored in raintanks.

Water Quality Results

Roofwater: One of the early monitoring priorities was to determine the quality of water in the roof to hot water system pathway. This priority arose from concerns expressed by approval agencies (see earlier Section). Roofwater was collected in the form of bulk and "first-flush" (first 2mm of rain) samples for five different roof aspects (west-north, west-south, south, east and north) over 40 rain events in July and August 1998. The samples were analysed for compliance with the chemical Guidelines listed in Table 1. The samples complied with the guidelines except for the parameters ammonia $NH_{3,}$ pH, chloride, iron and lead. A sample from each aspect was also tested for contamination by *Cryptosporidium* and *Giardia*, but no protozoa were detected in the samples.

Analysis of "first-flush" samples revealed the following Guideline exceedences: ammonia (68% of samples), pH (24%), iron (once) and lead (once). Analysis of bulk samples showed that Guideline values were exceeded as follows: ammonia (29%), pH (17%) and lead (twice).

Table 1: Water quality parameters monitored at Figtree Place

Chemical		Microbial	
Characteristic	**Guideline**	**Characteristic**	**Guideline**
NH_3	0.5 mg/L	Total Coliforms (TC)	0 mg/100 L
NO_3	50 mg/L	Faecal Coliforms (FC)	0 mg/100 L
NO_2	100 mg/L	Hetrotrophic 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		
pH	6.5 - 8.5		
Sulfate	250 mg/L		

Tank water quality results: Site inspections following the commissioning of Figtree Place found many construction irregularities including the disturbing realisation that the raintanks were holding water of very poor quality. These tanks had not been cleaned, first flush pits were not constructed and covers had not been sealed allowing entry of debris into the stored water. Ponding in roof and gutter system has also resulted from poor construction practices further compromising water quality.

Although these construction errors were expected to significantly compromise tankwater 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. Bacterial analysis of samples taken under these circumstances from raintanks at locations T1 to T4 shown in Figure 1 are summarised in Table 2.

Table 2: Results of bacterial analysis of raintank water (see Table 1 for explanation of symbols)

Date	Tank	Temp (^{0}C)	TC (/100mL)	FC (/100mL)	HPC (/1mL)	Ps (/100mL)
2/06/98	T1	14	1000	0	1190	11000
17/09/98	T1	14	0	0	100	85
18/10/99	T1	15	36	0	1388	28000
2/06/98	T2	14	30	0	30780	4500
5/08/98	T2	15	0	0	7410	1000
17/09/98	T2	14	25	0	14040	2900
26/08/99	T2	16	2	0	118	8000
18/10/99	T2	16	10	0	1616	40000
17/09/98	T3	15	340	6	1040	3900
26/08/99	T3	17	0	0	12	600
18/10/99	T3	18	3	2	2736	250800
17/09/98	T4	14	0	0	10	0
18/10/99	T4	16	15	8	2280	33200

The degree of bacterial contamination (Table 2) observed in each tank appears to be influenced by its location and the poor water quality integrity provided by the stormwater retention tanks. Tanks 2 and 3, located in common garden areas revealed generally poorer water quality than Tank 1 located in a footpath area of a private yard and Tank 4 located in an enclosed paved courtyard. Testing for *Cryptosporidium* and *Giardia* using samples taken in June and August 1998 showed negative results.

It is presumed that significant portions of recorded tank water bacterial concentrations were caused by soil falling into the tanks. The results for the bacterial parameters TC, HPC and Ps found in the tank water support this hypothesis. Redesign and reconstruction of many elements at Figtree Place was completed in September 1999. Unfortunately the roofwater retention tanks could not be replaced or repaired, however, they were cleaned (except Tank 1) and first flush pits were constructed. These construction activities resulted in more debris reaching the tanks: evidence of this is seen in the October 1999 results.

No exceedences of the guidelines (Table 1) for metals and chemical parameters were recorded in tank water although sampling of roof water by 50 litre drum and automatic sampler revealed exceedences for metals, chemicals and bacteria. Concentrations of bacteria in roofwater entering raintanks were typically two orders of magnitude greater than concentrations found in tankwater. Samples taken from the sludge on the bottom of tanks exceeded Guideline values for metal, chemical and microbial parameters supporting the assumption that contaminants were settling to the bottom of tanks and biofilms were extracting contamination from the tankwater.

This is an important preliminary finding. Significant water quality improvement is experienced within poor quality raintanks subject to regular contaminant loads from roofs and the surrounding soil. Settlement, flocculation and bio-reaction processes in the tanks appear to be removing contamination from roofwater. These processes are similar to those used to remove contamination from mains water supplies.

Hot water quality results: The tanks supply raw water to domestic hot water systems and toilets. Because there is a possibility that hot water may be accidentally used for drinking, it is considered essential to monitor its quality at the point of potential consumption. In addition to this monitoring, signs warning tenants not to drink from hot water taps were installed to minimize the risk of ingesting contaminated water.

Table 3 summarises hot water system bacterial results.

Table 3: Bacterial analysis of hot water from raintanks

Date	Tank	Temp (^{0}C)	TC (/100mL)	FC (/100mL)	HPC (/1mL)	Ps (/100mL)
2/06/98	T1	59	0	0	4	0
5/08/98	T1	58	0	0	0	0
26/08/99	T1	60	0	0	0	0
26/08/99	T2	55	0	0	0	0
19/10/99	T3	61	0	0	2	0
19/10/99	T2	63	0	0	4	0

Although rainwater collected in the tanks showed bacterial contamination (see Table 2), the same rainwater used in hot water systems in temperatures between 55^0 C and 63^0 C (see Table 3) was compliant with the Australian Drinking Water Guidelines (1996). These are promising findings given the concern expressed by approval agencies about the use of rainwater in hot water systems at Figtree Place. Hot water systems at Figtree Place are pasteurizing rainwater to produce acceptable water quality.

Other studies have shown that pasteurization is an effective method of removing bacterial contamination from water. Benenson (1995) reported that *Cryptosporidium* is eliminated within 2 minutes when the water is heated to 60^0 C, and within 20 minutes for water heated to 45^0 C. Jorgenson et al. (1998) found that *Faecal Coliforms* are eliminated from naturally contaminated river water when it is heated to 65^0 C. Joyce et al. (1996) found that *Faecal Coliforms* were eliminated from highly contaminated water (*Faecal Coliforms* count, 200,000 CFU/mL) subjected to a maximum temperature of 55^0 C over a period of 7 hours.

No exceedences of the guidelines (Table 1) for metals and chemical parameters were discovered in the hotwater samples. This result further supports the assumption that flocculation, settlement and bio-reaction processes are operating in the raintanks.

The efficacy of hot water systems to pasteurize rainwater depends on temperature and its duration. Figure 3 displays measured water temperatures over a period of one week for 2 electric hot water systems with 125 and 250 litre capacities and different usage patterns. These results are typical of the long term monitoring of hot water system performance.

The 125 litre capacity system, set at 60^0 C supplied hot water at an “off-peak II” rate to a 2-person household. The “off-peak II” rate heats water from 6am to 8am and from 8pm to 10pm. The average operating temperature was found to be 56^0 C, the maximum temperature 64.5^0 C and the minimum 30^0 C. The low temperature of 30^0 C coincided with a full bath rather than the usual shower taken by one of the occupants.

The capacity and operating mode of the hot water system was insufficient to maintain the hot water supply within a temperature range which will ensure bacterial compliance with the Guidelines. Removal of the bath event from the data gives a minimum operating temperature of 50.1^0 C.

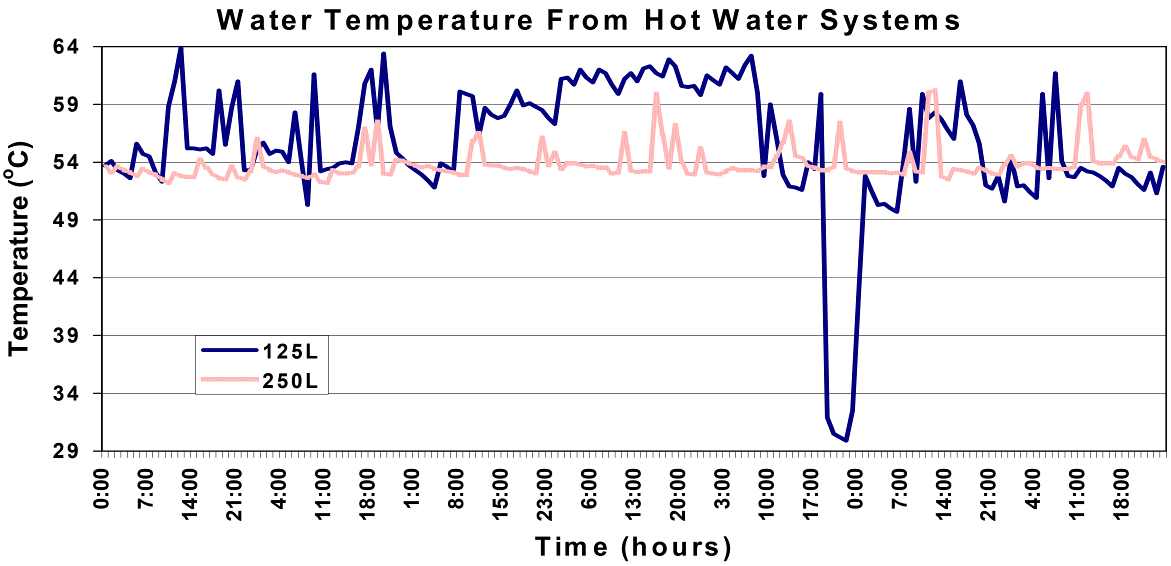

Figure 3: Water temperatures for two different hot water systems over a period of a week

The electric 250-litre capacity hot water system, set at 55^0 C, supplies water at an off-peak II rate to a 4 person household at Figtree Place. However, unlike the 125-litre system, it has a secondary element that will heat water to the set temperature at any time of the day. This type of hot water system is installed in the units at Figtree Place. The average operating temperature was found to be 53.7^0 C, the maximum temperature 60.2^0 C and the minimum temperature 51.8^0 C. This hot water system appears to have the capability to ensure reliable and acceptable water quality to the units.

Water Use, Social Acceptance and Stormwater Results

Measurement of internal water use at Figtree Place (partly occupied) during the period June to December 1998 showed a 65% reduction in expected mains consumption. During the period December 1998 to November 1999 the development was fully occupied but the tank water system was inoperative for long periods due to redesign/reconstruction activities. Nevertheless a 30% reduction in internal mains water consumption was experienced during this period. Based on these performances, it is anticipated that long-term **internal** water saving of about 45% will be recorded at Figtree Place. This confirms the expectations of Argue (1997) and Mitchell et al. (1997) for water saving using rainwater stored in tanks and used in hot water systems and for toilet flushing.

Surveys of 26 tenants by questionnaire revealed significant acceptance (95%) of the use of rainwater collected from roofs for toilet flushing and hot water systems, clothes washing and cooking. Moderate acceptance (70%) of the possible use of rainwater for drinking purposes was also found.

Cameron et al. (1999) established that the concept of WSUD was popular with construction industry professionals and the community. However dissemination of information from demonstration sites is required to overcome negative myths about and institutional resistance to the use of infiltration techniques and raintanks as source control measures in urban areas.

An unexpected but much commented upon benefit of Figtree Place is a strong sense of community, security and amenity derived from the layout of the development which is centered on a common open space area (Coombes et al., 1999a).

There has been no stormwater overflow from the site during the life of the project and a maximum depth of ponding in the detention basin of 260 mm with a residence time of 6 hours has been experienced.

Project Cost Effectiveness

Much has been learnt about the design, management and maintenance of the Figtree Place demonstration project during the initial period of operation. 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 sites [Coombes et al., 1999a].

In the approximate economic analysis presented below costings are based on the existing system. However, our experience has pointed to improved designs that are less expensive. These improved designs are not addressed here.

Basic project costs are as follows:

development cost (27 units, etc.) :	$2,700,000
"water-sensitive" design elements (raintanks, pumps, recharge basin and plumbing):	$89,600
alternative conventional stormwater system elements ("greenfield" site):	$115,500

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 expected annual water saving for Figtree Place and the adjacent Bus Station is calculated as follows:

total water saving (residences) :	1190 kL/annum
irrigation saving:	830 kL/annum
bus-washing saving:	1,700 kL/annum
Hunter Water Corp. charges:	$0.92 kL/annum
hence, expected overall savings :	$3422 per annum.

Assuming that the savings are invested for a ten year period using a discount rate of 6% the annual value of the construction savings is $3478. The approximate annual value of the cost saving at Figtree Place (alone) is therefore:

Water savings:	$1858
Annual investment saving:	$3478
Less annual depreciation and maintenance costs:	$1300
Total annual saving:	**$4036**

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

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 currently taking place using Figtree Place as an example of "new practices". Detailed analysis of opportunity cost savings of delayed augmentation of infrastructure resulting from implementation of WSUD principles and a discussion of externalities will be published in the near future.

The cost savings to the community from such implementation are perceived to be significantly greater than the site benefits estimated in this paper. Andoh and Declerck (1999) found that retention and infiltration measures used as source controls reduced infrastructure maintenance and rehabilitation cost by a factor of five and also significantly reduced pollution of receiving waters.

Operation of the Figtree Place demonstration project has revealed opportunities for improved design in the form of reduced plumbing, elimination of backflow prevention devices, exclusion of redundant elements and more efficient construction practices. An existing housing allotment in Maryville, a suburb of Newcastle, Australia is currently being fitted with WSUD elements (rainwater tank and retention trench) to investigate costs and performance of improved design practices that have resulted from the Figtree Place experience.

Conclusions

This paper summarises early results from the Figtree Place demonstration project. Although experience has revealed significant flaws in the construction/design of the project much has been learnt from "worst case scenario" monitoring and analysis. Some important conclusions that support implementation of WSUD 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 55°C and 63°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 hotwater system is an effective water treatment process that produces water quality results compliant with drinking water guidelines.
- The use of roofwater collected in raintanks for hot water systems and toilet flushing is expected to yield residence **internal** water savings of around 45%.
- **Total** water savings of Figtree Place, compared with an equivalent conventional development, are expected to be around 60 %: this includes irrigation;
- 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.

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