BDP ENVIRONMENT DESIGN GUIDE

STRATEGIC USE OF STORMWATER

Peter Coombes and George Kuczera, Department of Civil, Surveying and Environmental Engineering, University of Newcastle

Abstract

Reuse of stormwater and roofwater can provide substantial benefits to the community including reduced mains water use, stormwater discharges and impact on the environment. Strategies for the capture and reuse of stormwater and roofwater are discussed in the context of government policies and regulations, Australian Standards and public health requirements in this article.

1.0 Introduction

The urban water cycle starts with water extracted from streams and aquifers, stored in reservoirs and then processed to potable quality before delivery through an extensive pipe system to consumers. Some of this water is then used to transport wastes through a network of sewers to treatment plants which discharge effluent into receiving waters such as rivers, lakes and oceans. Rainfall falling on the consumer's allotment contributes to the urban catchment's stormwater, and is collected by an extensive drainage system for disposal into receiving waters.

At the allotment all three components of the urban water cycle meet with water consumed and storm and wastewater discharged. Source control through management of the cycle at this level offers the opportunity to provide benefits for the consumer and the environment. The philosophy of source control is to minimize cost-effectively the consumption of mains water and the production of storm and wastewater. Source control can be implemented through retention of roof rainwater (rainwater tanks), stormwater detention, on-site treatment of greywater (laundry, bathroom and kitchen) and blackwater (toilet), use of water efficient appliances and practices, and on-site infiltration. While there has been considerable research into source control technologies, largely pioneered by Argue [1986], little work has focused on detailed assessment of the economic and environmental benefits.

Authors such as Clarke [1990], Mitchell et al. [1997], Argue et al., [1998], and Kuczera and Coombes., [2001] suggest the adoption of source control measures to reduce infrastructure costs and environmental impacts. Less than 4% of urban water consumption is used for drinking. However, all mains water supply is treated to potable quality [Mitchell et al., 1997]. Considerable scope exists for the strategic reuse of stormwater (and rainwater) for second quality uses (including toilet flushing, outdoor, laundry and hot water).

The traditional urban drainage paradigm involving use of more and bigger capacity pipes to discharge stormwater runoff as quickly as possible results in costly solutions and adverse environmental impacts. The use of source control measures can result in cost savings of 30% to 80% over traditional stormwater drainage measures [Andoh and Declerck ,1999]. In Germany rainwater tanks are subsidised and are used to supply water for toilet flushing and irrigation to avoid the development of new water resources [Schilling and Mantoglou,1999]. The strategic reuse of stormwater (and rainwater) has the potential to provide significant benefits across the entire urban water cycle.

2.0 Policies and Regulations

The use of stormwater management measures in the urban environment is currently dominated by Local Government interpretation of Australian Rainfall and Runoff [IEAust, 1987]. Unfortunately Australian Rainfall and Runoff is largely about flood estimation and the design of pipe drainage systems therefore approval of sustainable stormwater management practices (such as rainwater and stormwater reuse) by Council officers can be difficult to obtain. The design of stormwater and rainwater reuse practices may also have to consider Australian Standards such as AS3500.1.2 Water Supply: Acceptable Solutions, water quality regulations from State Government Health Departments and the Australian Drinking Water Guidelines [NHMRC, 1996].

2.1 State Government Health Departments

State Government Health Departments do not prohibit the use of rainwater for drinking or other purposes. They recommend proper use and maintenance of rainwater tanks, and provide a monograph

'Guidance on the use of rainwater tanks' [Cunliffe, 1998] to assist with this task. Although rainwater can be used for many purposes, the focus of Department of Health guidelines is drinking water quality. No water quality guidelines exist for second quality uses (including outdoor, toilet, laundry and hot water uses).

2.2 Water Authorities

Water authorities cannot prohibit the reuse of rainwater or stormwater on private land. Their primary concern is to maintain the quality of mains water. Accordingly, water authorities require the installation of an appropriate backflow prevention device or method to prevent contamination of mains water by rainwater or stormwater [ASNZ3500.1.2].

2.3 Local Government

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

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

Local councils cannot prohibit the reuse of rainwater or stormwater. However, where a council is a water supply authority, it can require the installation of an appropriate backflow prevention device.

2.4 Australian Standards

Two Australian standards, namely the *Australian Drinking Water Guidelines [NHMRC, 1996]* and *AS/NZS 3500.1.2 National Plumbing and Drainage: Water supply - acceptable solutions*, provide guidance for stormwater and rainwater reuse. The Australian Drinking Water Guidelines provides little assistance on reuse of stormwater for secondary quality purposes because its focus is drinking water quality. Chapter 7 advises on the management of small potable water supplies, and Cunliffe [1998] provides a complete coverage of the topic.

AS/NZ 3500.1.2 provides useful guidance for the design stormwater and rainwater reuse systems. Cross connection between mains water supply and premises with a rainwater tank is described as a low hazard requiring a non-testable backflow prevention device, indicating that rainwater can be considered to be potable. The hazard rating of stormwater is not categorised although cross connection between mains water and grey water is considered to be a medium hazard. Thus assigning a medium hazard rating to stormwater would seem logical. A number of backflow prevention devices can be used including an air gap and a Reduced Pressure Zone Device (RPZD). An air gap is the provision of a physical separation between the mains water and the rainwater supplies within a storage. This is a simple, maintenance free and reliable solution. The RPZD is a mechanical device to separate mains and other water supplies that requires servicing and replacement.

The standard provides guidance for the design of rainwater tanks with dual water supply (rainwater and mains water) [Section 8.5]. Rainwater tanks with dual water supply can maintain an air gap, and be designed and connected as shown in Figure 1. Alternatively a dual supply system using stormwater or rainwater could use a RPZD and mains water bypass as shown in Figure 2.

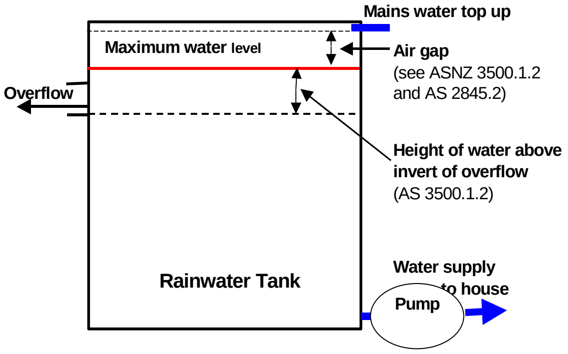

Figure 1: design details to prevent backflow for a rainwater tank with mains water top up

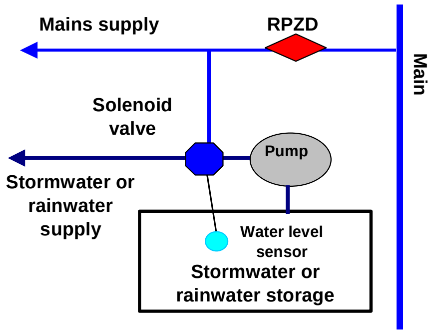

Figure 2: design details to prevent backflow using a RPZD for a stormwater storage with mains water by pass

3.0 Quality of Rainwater Collected from Roofs and Stored in Tanks

There are many misconceptions about the quality of water from rainwater tanks. In order to understand the origins of these misconceptions one must take a historical perspective. The early debate about the quality of water from domestic rainwater storages was propagated for economic reasons. Armstrong [1967] and Lloyd et al. [1992] explain that early water authorities were in debt. Acts of Parliament were created in the 1800s requiring the occupiers of all properties to pay for mains water supply even if they did not use it to ensure that government debt was repaid. The reluctance of the community to part with their rainwater storages had threatened the economic viability of the new centralised water supply paradigm. The legislated mandatory fixed charges ensured that citizens used mains water in preference to household rainwater tanks. Public health concerns were used to justify the enforced removal of rainwater tanks from many early homes to ensure the economic viability of the new water authorities.

The arguments predominately used to discourage the use of rainwater are public health concerns although very few published studies or data are in existence to justify this position. Indeed over 3 Million Australians currently use rainwater from tanks for drinking [ABS 1994] in urban and rural regions with no reported epidemics or wide spread adverse health effects. Fuller et al., [1981] and Mobbs et al., [1998] found that the quality of rainwater was often adequate for potable uses. Coombes et al., [2000b] reported that that rainwater collected from roofs in an inner city industrial area and stored in tanks was of acceptable quality for hot water, toilet and outdoor uses. Although roof runoff and the surface of stored water was sometimes found to be contaminated, the quality of water at the point of supply in rainwater tanks was significantly improved. The Namoi Valley Public Health Unit [Bell G., personal communication, 1999] and The Newcastle Public Health Unit [James J., personal communication, 1999] also reported that the quality of rainwater improved in rainwater tanks. Rainwater used in hot water systems (temperature settings: 50ºC to 65ºC) was found to be compliant with Australian Drinking Water Guidelines [Coombes et al., 2000b].

However some studies suggest that drinking rainwater collected from roof surfaces is a potential source of human illness. Simmonds et al., [2001] failed to find *Campylobacter* in roofwater in Auckland therefore they could not support the assumption that birds contributed to faecal contamination of roof surfaces. They also did not detect *Legionella Spp.* Although it was found that the rainwater supplies sometimes exceeded drinking water guidelines for lead and microbial indicator organisms. Importantly the presence of potential pathogens *Salmonella Spp.* and *Cryptosporidium* were detected in one and two samples respectively. No illness was reported. Taylor et al., [1999] attributed an outbreak of Salmonella to the presence of frogs and mice in a poorly maintained rainwater tank on a building site in Rockhampton. Gee [1993] reported exceedance of drinking water guidelines for microbial indicator organisms and pH in water from poorly maintained rainwater tanks in the Sydney region although rainwater was sampled from the water surface rather than the point of supply.

A detailed discussion about the microbial and biochemical aspects of mains water and rainwater, and the subsequent health implications is beyond the scope of this article. However it should be obvious from the above discussion that the production of mains water or rainwater for drinking purposes requires careful management of the water source. Likely sources of contamination in rainwater tanks are soil and leaves accumulated in gutters for long periods, faecal material deposited by birds, lizards, mice, rats, possums etc., and dead animals in gutters or tanks.

Acceptable water quality can be maintained in a rainwater tank provided that mesh screens cover all inlets and outlets to limit access of leaves, debris, animals and mosquitoes to the tank, a first-flush device is used to discard the first part of rainfall that may be contaminated, and roof gutters are regularly cleared of leaves and debris. Rainwater should not be collected from roofs painted with lead based paints or tar based paints or from roofs constructed using asbestos. Roofs constructed from galvanised iron, Colorbond, Zincalume, slate or ceramic tiles provide acceptable water quality. Special roof guttering in not required for rainwater collection, normal guttering is sufficient provided that the roof guttering is kept clear of leaves and debris.

Another method to eliminate possible health risks of the use of water from rainwater tanks is to use rainwater for purposes other than drinking. The designer can match different household use categories with the required water quality, frequency of use and rainfall to maximise water savings. The proportion of typical domestic household uses is shown in Figure 3.

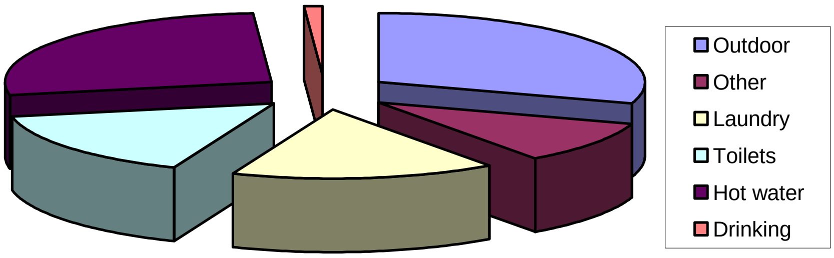

Figure 3: Domestic water use types by proportion

Figure 3 reveals that drinking water is a very small proportion of total household water use. It is clear that an effective strategy for rainwater or stormwater reuse to reduce mains water consumption could target household consumption types with greater volumes and frequency of water use that required a lesser water quality (such as outdoor, toilet, laundry or hot water uses).

However a mistake commonly made by designers is to assume that using rainwater to supply outdoor uses will produce substantial mains water savings. The mismatch between seasonal rainfall and outdoor water use patterns results in poor utilisation of rainwater resulting in long periods when the tanks are either empty or full. This problem can be remedied by using rainwater to supply a constant inhouse use such as toilet flushing that will consistently draw down the rainwater storage allowing the rainwater to refill the storage more often. Combinations of different water use frequencies from rainwater tanks such as toilet flushing and outdoor uses can result in optimum mains water savings.

4.0 Reuse of Roofwater and Stormwater at the Allotment Scale

The allotment is the building block of the urban stormwater catchment. Impervious surfaces in stormwater catchments increase peak and volumetric stormwater discharges, the frequency of downstream flooding, and the frequency of sewer surcharges to waterways. About 75% of impervious surfaces in an urban catchment are in the allotment and 70% of those surfaces are roofs. Clearly the allotment is a major contributor to flooding and water quality problems in urban catchments. However traditional design practices are dominated by street drainage and end of pipe measures ignoring stormwater mitigation opportunities on allotments. An excuse often given for discharging roofwater directly to street gutters is that it is relatively clean. However, “clean” roofwater discharged directly to the street gutter can acquire considerable kinetic energy, which can act within the catchment to erode soils and carry contaminants to waterways. A sustainable stormwater management strategy for an urban catchment needs to carefully consider mitigation opportunities on allotments. Capture and reuse of roofwater and stormwater is an effective stormwater management method that provides an additional benefit of mains water use reduction.

A distinction must be made between the reuse of **roofwater** (rainfall that is directly collected as the roof runoff from buildings) and the reuse of **stormwater** (rainfall that is collected after it runs off urban areas such as roofs, paved and vegetated surfaces). The quality of roofwater is typically better than stormwater allowing a wider variety of reuse opportunities.

4.1 Reuse of Roofwater

Rainwater collected from roofs and stored in tanks or Rainsaver roof gutters can be an excellent source of water for indoor and outdoor uses. Design of the roofwater system will depend on a number of factors including:

- the proposed uses of the roofwater (drinking, toilet flushing, laundry, outdoor use),

- the objective of the roofwater system (stormwater management, mains water demand management or other objectives),
- whether the storage is above or below ground, and
- whether the roofwater system will form part of a dual water supply scheme (mains water and roofwater) or will the roofwater system be independent of the mains water supply.

The design objectives of the roofwater system and the water quality requirements, will govern the end uses of the roofwater. A rainwater tank will only provide significant reduction in mains water use and stormwater discharge when the tank water level is constantly drawn down. This can be achieved by using the roofwater to supply indoor uses such as toilet flushing, hot water or clothes washing as well as outdoor uses. Considerable reduction in mains water use (up to 65%) and stormwater discharges (up to 55%) can be achieved with tank sizes between 5,000 L and 15,000 L, provided that roofwater is used for indoor purposes and a dual water supply strategy is implemented [Mitchell et al., 1997, Coombes et al, 2000, 2001 & 2001a, Coombes and Kuczera 2001]. There are many methods to establish a dual water supply scheme. A dual water supply scheme is the use of roofwater and mains water stored in a tank to supply a particular use. The three most common methods are:

- to top up the rainwater tank with mains water from a garden hose when the tank empties [Mobbs, 1998],
- to trickle top up the rainwater tank with mains water to a minimum level when the rainwater tank water level falls below the minimum level [Coombes and Kuczera, 2001]. A mechanical float system is used to control the trickle top up and an air gap (Figure 1) is used for backflow prevention, and
- to switch between mains and tank water supply using a solenoid valve and a water level sensor in the rainwater tank. When the rainwater tank is empty mains water is used to supply all uses [Coombes et al, 2000]. A reduced pressure zone device (RPZD) is used for backflow prevention in this configuration (Figure 2).

The dual water supply solution involves the use of moderate sized rainwater tanks and pumps. A roofwater supply system that is independent of the mains water system will need larger rainwater tanks to provide an acceptable reliability. Alternatively a relatively small rainwater tank (up to 2000 Litres) is required to supply drinking water in most Australian climatic conditions. The designer should consult with the relevant State Department of Health for advice on the use of rainwater for drinking. The State Departments of Health provide the monograph “Guidance on the Use of Rainwater tanks” by Cunliffe [1998].

An important aspect of roofwater system design is water quality matching. The roof to gutter to rainwater tank to household use pathway for roofwater is a treatment chain. The roofwater systems at the Figtree Place and Maryville developments in NSW provided acceptable water quality for toilet flushing and hot water uses [Coombes et al., 2000b]. Both developments did not have effective first flush devices or special gutter systems. The quality of roofwater was found to improve in the rainwater tanks due to the processes of settlement and bio-reaction, and to further improve in hot water systems due to pasteurisation (lethal temperature) and tyndallization (small perturbations in water temperature). Indeed roofwater quality in hot water systems (temperature range 50ºC to 65ºC) was always compliant with the Australian Drinking Water Guidelines.

At the sustainable house in Sydney (see CAS 12), roofwater is used to supply all potable uses including drinking water. The design of roofwater treatment chain included the use of Smartflow roof guttering, a leaf diverter on downpipes, first flush separation, a settlement pit, a rainwater tank and a water filter for drinking water [Mobbs, 1998].

The healthy home in Queensland uses roofwater collected in a rainwater tank to supply all potable uses [Gardner et al., 2001]. When the rainwater tank is empty mains water is used to supply potable uses. The roofwater treatment chain at the Healthy Home included a first flush separation device, the rainwater tank, and a 20 micron water filter. An ultra violet disinfection unit was added to the treatment chain because microbial activity was detected in the rainwater tank immediately after rainfall events. The design of a roofwater treatment chain will depend on the proposed water uses. The following roofwater treatment chains are proposed:

- Outdoor, toilet and hot water uses: first flush separation device and rainwater tank.
- Indoor uses (excluding drinking water): first flush separation device, Enviroflow roof gutters (or equivalent) or regular cleaning of roof gutters and the rainwater tank.
- Drinking water: first flush separation device, Smartflow roof gutters (or equivalent) or regular cleaning of roof gutters, a rainwater tank and a water filter or a ultra violet disinfection unit.

A first flush device will also divert sediment from entry to the rainwater tank. In each case overflow from the rainwater tank can be directed to the street drainage system, to an infiltration trench or a landscaped stormwater retention measure.

A Rainsaver roof gutter system can also be installed to facilitate roofwater reuse for toilet flushing and outdoor uses. The Rainsaver roof gutter includes a perimeter tank that stores 25 litres of roofwater per linear metre of gutter. The gutter is directly connected to toilet cisterns and garden hoses. Roofwater enters the gutter via a leaf guard and flows through mosquito proof supply holes into a storage gutter ready for use in the toilet or the garden. Research from the University of South Australia shows that use of a Rainsaver gutter system will provide about a 25% reduction in mains water demand and a 45% reduction in roofwater discharge to the street drainage system in an average household. About half of the roofwater retained in the Rainsaver gutter was observed to overflow into garden areas. A design using a Rainsaver gutter system must include a strategy to absorb or utilise overflows.

4.2 Reuse of stormwater

Stormwater runoff from roofs, paved and garden areas can be captured in underground tanks, ponds or infiltration systems for active or passive reuse. An ancient example of integrated water supply is the capture of roofwater in an above ground tank for drinking and cooking uses. Overflow from the above ground tank and stormwater runoff from paved and grassed surfaces was captured in a pond or underground tank [Pacey and Cullis, 1991]. Stormwater from the pond or underground tank is used to supply all other water uses. Ancient stormwater management practices involving the capture and reuse of as much stormwater as possible are the antithesis of modern practice, as described for example in Australian Rainfall and Runoff [IEAust, 1987], that encourages rapid discharge of stormwater to the environment. It is ironic that sustainable stormwater management practice has rediscovered ancient practices. There are many strategies for reuse of stormwater at the allotment scale, including:

- direct roofwater and stormwater to gardens or lawns rather than the street drainage system,
- capture overflow from rainwater tank and stormwater in ponds and reuse for outdoor and toilet uses
- capture overflow from rainwater tank and stormwater in underground tanks and reuse for outdoor and toilet uses,
- direct roofwater and stormwater to a gravel filled infiltration trench. A shallow gravel layer adjacent to or under a garden area will provide passive irrigation to the area [Argue et al., 1998], and
- direct roofwater and stormwater to water sensitive gardens that may include ponds, swales, contour banks, infiltration measures and mulching [van Gelderen, 1998] (DES 19).

Unlike traditional pipe based stormwater management there is no recipe for an effective source control design. The approach lends itself to the collective wisdom of design teams that include architects, engineers, landscape architects and ecologists. Ideally the source control solution will allow the built environment, its function and the environment to become an enhancement to the urban landscape. Knowledge of the climate, terrain, soil type, geology and the receiving water environment is important to the design process. The designer should carefully consider the issue of sediment management, particularly during the construction phase of the development.

5.0 Strategies for Reuse of Stormwater at the Subdivision Scale

At the subdivision scale sustainable stormwater management includes conveyance controls such as grass swales, water sensitive road design and natural waterways; and storage methods that include detention basins, infiltration basins, constructed wetlands and aquifer recharge. These storage methods offer opportunities for stormwater reuse for irrigation of parklands, sporting fields and for cluster housing groups. There are many different methods for stormwater reuse including:

- capture of stormwater in urban lakes for outdoor reuse,
- capture of stormwater in urban lakes or cluster scale tanks for outdoor and toilet reuse,
- aquifer storage and recovery,
- constructed wetlands,
- water harvesting, and
- industrial reuse.

Urban lakes are usually constructed lakes within the urban area that are used to capture, store and treat stormwater for outdoor reuse on gardens and lawns. The lakes also improve urban amenity and provide habitats for flora and fauna. Stormwater can also be captured in urban lakes or housing cluster scale tanks for reuse in toilets and gardens in households.

Aquifer recharge is the capture and treatment of stormwater for injection or discharge to a suitable aquifer. Stormwater can be captured in urban lakes, wetlands, dry basins or gravel trenches and allowed to percolate to an aquifer or can be injected via a bore into an aquifer. The stormwater is stored in the aquifer for subsequent reuse to meet outdoor water demand at a later date. Successful examples of this technique include the Figtree Place development [Coombes et al., 2000], the New Brompton Estate [Argue et al., 1998] and the Mawson Lakes development [Gardner et al., 2001].

Constructed wetlands are similar to urban lakes except they also contain selected grasses and aquatic reed beds designed to improve stormwater quality. Stormwater stored in constructed wetlands can be reused for outdoor purposes. Water harvesting involves the capture and storage of stormwater during periods of considerable stormwater runoff or streamflow. The stormwater runoff or streamflow is directed to an offline urban lake or wetland for subsequent reuse for outdoor purposes. Stormwater captured in urban lakes, wetlands or by aquifer recharge and storage can also be reused for industrial purposes such as cooling, boiler and process water, and for wash down purposes.

6.0 Design of Rainwater Tanks for Water Supply and Stormwater Management with Some Systems Implications.

Rainwater tanks can be installed to housing in many above and below ground configurations to supply various domestic uses. Little or no literature exists on the design of rainwater tanks for water supply and stormwater management. A method used by the University of Newcastle [Coombes and Kuczera, 2001] to design demonstration projects (such as the Maryville site) is outlined below to assist with this task.

6.1 Installation of a Rainwater Tank

In order to maximise water savings and stormwater management benefits, rainwater tank capacity will be between 5,000 L and 15,000 L for each residential dwelling although smaller tank sizes also can provide considerable benefits. The required capacity will depend on number of persons in the household, water use, rainfall and roof area. The design outlined below is for a tank on the ground solution therefore it is also important to consider the site area available for the tank. Many authors have assumed that rainwater tanks will occupy a large area and recommend underground tanks at considerable cost. However rainwater tanks occupy very little space. A rainwater tank with a capacity of 5,000 L will occupy an area of about 2 m^2 and a tank with a capacity of 15,000 L will occupy an area of 6 m^2. Design of the roofwater reuse scheme (Figure 4) should make provision for:

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

The minimum storage volume is the maximum daily water use that is expected from the tank (about 250 -750 litres). If the volume of stored water falls below the minimum storage volume, the shortfall can be overcome by topping up the tank with mains water to the required level. A simple float valve system can be installed to do this automatically.

The rainwater storage volume is the total volume available in the tank to store rainwater below the overflow pipe. The air space between the overflow pipe and the top of the tank can be used to provide 'stormwater detention', thereby delaying the delivery of excess roof water to the drainage system. The rainwater storage volume and the overlying air space both provide stormwater management benefits providing both retention and detention of roofwater. The required volume for the air space will vary according to the selected average recurrence interval (ARI) 'design storm' [IEAust, 1987].

The configuration of plumbing required for rainwater tanks is shown in Figure 4. Water supply from the rainwater tank (such as for outdoor, toilet, laundry or hot water uses) is directed to the household via a small pump. When tank water levels are low, such as during hot, dry periods, the tank is topped up with mains water via a trickle system. The trickle top up system will reduce the daily peak demand on the mains water distribution network. In the event of pump or power failure the rainwater tank can be bypassed.

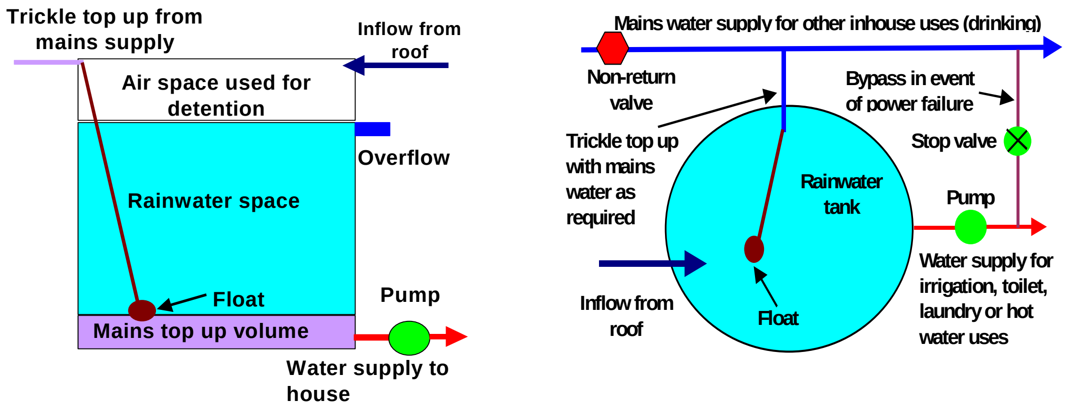

Figure 4: design details for a dual water supply system using rainwater and mains water

The installation of the rainwater tank is fairly simple. The ground surface at the location chosen for the tank is levelled and a 100 mm thick reinforced concrete slab constructed. After the concrete has set place the tank on the slab with the tap, overflow pipe and outlet pipe orientated in the desired directions. A plumber should be commissioned to install the pump, pipes from the roof gutters, the first flush device and water supply pipes to the appliances that will use tank water (such as toilets, hot water systems and laundry taps). To avoid the risk of cross connection between mains water and rainwater the pipes from the tank are plumbed directly to appliances that are to use rainwater. The plumber should also install the mains water trickle top up and float system. An electrician may be needed to install a power point close to the pump.

6.2 The First Flush Separation Device

A first flush device that will separate the first 0.3 – 0.5 mm of rainfall is recommended. Many authors [including Jenkins and Pearson, 1978, Mitchell et al., 1997, Yaziz et al., 1989 and Cunliffe, 1998] describe the first flush as a fixed amount of roof runoff (the first 0.3 – 0.5 mm of rainfall) requiring separation. The first flush pits at Figtree Place were designed to separate the first 2 mm of roofwater from inflow to the rainwater tanks [Coombes et al., 2000]. The first flush pits proved to be so efficient that no inflow to the rainwater tanks resulted. Design of first flush separation devices need to maximise conservation of roof water and minimise contaminant transport to the rainwater tank. The conceptual design of a first flush device (Figure 5) includes an inlet from the roof, a chamber to capture the first flush of rainwater allowing it to leak through a small hole in the base of the chamber, a mesh screen to separate debris and an overflow to the rainwater tank.

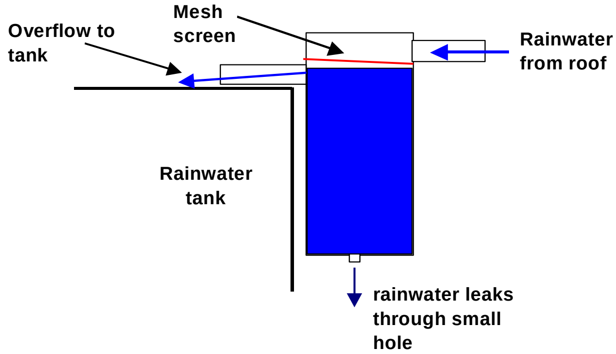

Figure 5: Diagram of the first flush separation concept

6.3 Costs to Install and Operate the Rainwater Tank

The cost to install a dual water supply system including a 10,000 L Aquaplate rainwater tank with a Davy pump to an existing house (the Maryville demonstration site) has been reported in Coombes et al., [2000]. The current costs for installation of different rainwater tank sizes, in Australian dollars, are shown in Table 1.

Table 1. Cost to install a rainwater tank system

Item	Cost to install each tank size ($)		
	5 kL	**10 kL**	**15 kL**
Aquaplate rainwater tank	540	870	1200
Pump + pressure controller	200 + 160	200 + 160	200 + 160
Plumber and fittings	500	500	500
Float system	100	100	100
Concrete base	200	200	200
GST	170	200	240
Total	**1910**	**2230**	**2600**

The lifecycle costs of the rainwater reuse solution are: pump costs about $0.001 per day to operate and has a 10 year life, and the rainwater tank has a 50 year life. The operating and maintenance costs for the pump can be assumed to be $0.1 per 1000 L of rainwater consumed [Coombes and Kuczera, 2001].

Stormwater or roofwater reuse can provide substantial cost savings for the construction of stormwater water infrastructure in new developments. The Figtree Place development provided a 1% cost saving ($960 per dwelling) in stormwater infrastructure [Coombes et al., 2000]. Kuczera and Coombes [2001] found that roofwater reuse in a new development would reduce the need for stormwater pipes and end of pipe water quality devices resulting in a 3% cost saving (including the cost to install rainwater tanks).

The reuse of stormwater or roofwater can also have significant impact on the provision of water supply headworks and distribution infrastructure. Research shows that the introduction of rainwater tanks to supply domestic toilet, hot water and outdoor uses will significantly defer (38 – 100 years) the need to construct new dams in the Sydney, Lower Hunter and Central Coast regions of NSW [Coombes et al., 2000a and 2001a]. It was also found that the use of rainwater tanks with mains water trickle top can reduce annual maximum daily peak demands by up 40% for domestic dwellings [Coombes et al., 2001b]. This can reduce the cost of water distribution (pipes) infrastructure.

Unfortunately these infrastructure cost savings can only be realised if approval authorities accept that stormwater and roofwater reuse provides water supply and stormwater management benefits thereby reducing the requirement for centralised infrastructure. The pipe system recipes derived from Australian Rainfall and Runoff [IEAust, 1987] and pipe discharge based models dominate local government assessment of stormwater management solutions. The recipe or models with discharge philosophies rather than storage philosophies cannot provide reliable guidance for approval authorities.

Evaluating the impact of stormwater or roofwater reuse on the urban water cycle is an extremely complex task. Yet the historical evaluation of such impacts has been dominated by 'back of the envelope' calculations, the use of untested assumptions and institutional constraint. There are many 'classic' untested assumptions about roofwater reuse. A common argument used to claim that rainwater tanks do not provide stormwater management benefits is that the tank will have no storage available prior to a storm event. Monitoring and analysis by the University of Newcastle finds this assumption to be incorrect. Coombes et al., [2001b] found that rainwater tanks used to supply toilet, hot water and outdoor uses will have 42% of their capacity available for roofwater retention prior to a 100 year ARI storm and will reduce peak stormwater discharges by about 80% for the one year ARI storm event in the Parramatta region of NSW.

Fortunately new models and design methods for stormwater and roofwater reuse technologies are being developed by the Australian research industry. The Aquacycle model [Mitchell et al., 1997] (available from the CRC for Catchment Hydrology) allows the designer to understand daily water balances. The allotment water balance model [Coombes and Kuczera., 2001] (currently being beta tested by Brisbane City Council) operates at small time steps allowing understanding of the impact of stormwater or roofwater reuse on water supply and stormwater infrastructure. The WUFS (Water Urban Flow Simulator] model by Kuczera et al., [2001] is for design of traditional pipe and water sensitive approaches for subdivisions or catchments.

7.0 Retrofitting Opportunities and Economic Implications

Retrofitting of sustainable stormwater management elements to developed areas can be difficult and appear to be expensive. However these measures also present opportunities for catchment repair in urban areas subject to environmental stress and loss of serviceability from aging or overloaded infrastructure. The urban allotment presents the most promising opportunity for installation of stormwater and roofwater reuse technologies in developed areas. The small-scale nature of source control solutions allows relative ease of installation. It is far easier to install a rainwater tank with an area of 2 – 6 m^2 in a number of allotments than to construct an urban pond with an area of 200 – 2000 m^2 in a fully developed catchment.

Installation of stormwater and roofwater reuse elements cannot replace the need for urban water cycle infrastructure in a fully developed urban catchment. However, it can substantially reduce the load on water cycle (stormwater, wastewater and water supply) infrastructure. As a result, the service life of water cycle infrastructure (pipes, treatment plants and dams) can be substantially increased resulting in significant long-term savings. The current short-term nature of economic analysis results in the illusion that retrofitting opportunities are expensive. Lifecycle analysis of urban water cycle infrastructure with retrofitting of stormwater and roofwater reuse measures reveals large economic and environmental savings to the community [Clarke 1990, Andoh and Declerck 1999 and Coombes et al., 2000a, 2001a].

8.0 Conclusion

The benefits of source control approaches such as stormwater and roofwater capture and reuse arise from reduced demand on water supply and stormwater infrastructure. Rainwater tanks contribute significantly to these benefits. Water levels in rainwater tanks used to supply domestic inhouse and outdoor 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.

Strategies for the capture and reuse of stormwater and roofwater in the context of government policies and regulations, Australian Standards and public health requirements have been provided in this article.

References

ABS., (1994). Environmental issues: people's views and practices. Catalogue No. 4602.0. Australia

Andoh, R.G.H., and Declerck C., (1999). Source control and distributed storage – A cost effective approach to urban drainage for the new millennium? 8th Int'l Conf. on Urban Storm Drainage, 1997-2005, Sydney.

Argue, J. R., (1986). Storm drainage design in small urban catchments: a handbook for Australian practice. Special Report No. 34, Australian Road Research Board, Vermont South.

Argue, J. R., Geiger W.F., and Pezzaniti D., (1998). Demonstration projects in "Source Control" technology: theory and practice. Hydrastorm98 Int'l Symp on Stormwater Management, 419-424, I.E.Aust.

Armstrong J.W., (1967). Pipelines and people. Halstead Press. Sydney

AS/NZS3500.1.2, (1998). Water supply: acceptable solutions

Clarke, R.D.S., (1990). Asset replacement: Can we get it right? Water, 22-24, February.

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

Coombes, P.J., Kuczera, G. and Kalma, J.D., (2000a). Economic benefits arising from use of water sensitive urban development source control measures, 3rd Int'l Hydrology and Water Resources Symp., Inst. Eng. Aust., Australia, Perth, 152-160.

Coombes, P.J., Kuczera, G. and Kalma, J.D., (2000b). Rainwater quality from roofs, tanks and hot water systems at Figtree Place, 3rd Int'l Hydrology and Water Resources Symp., Inst. Eng. Aust., Perth, 1042-1047.

Coombes P. J., and Kuczera G., (2001). Rainwater tank design for water supply and stormwater management. Stormwater Industry Association Regional Conference. Port Stephens. NSW.

Coombes, P.J., Kuczera, G., Argue, J. and Kalma, J.D., (2001a). An evaluation of the benefits of source control measures at the regional scale. Urban Water, in review.

Coombes P.J., Frost A., and Kuczera G., (2001b). Impact of rainwater tank and on-site detention options on stormwater management in the Upper Parramatta River Catchment. Research Report. Department of Civil, Surveying and Environmental Engineering. University of Newcastle.

Cunliffe D. A., (1998). Guidance on the use of rainwater tanks. National Environmental Health Forum Monographs. Water Series No. 3. South Australian Health Commission. Glenelg Press. Adelaide.

Fuller C. A., Martin T. J., and Walters R. P., (1991). Quality aspects of water stored in domestic rainwater tanks (a preliminary study). Domestic Rainwater tanks Working Party. South Australia.

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

Gee L., (1993). Pilot survey of the microbiological and chemical aspects of water stored in domestic rainwater tanks. Western Sector Public Health Unit. Sydney.

IEAust. (1987). Australian rainfall and runoff. A guide to flood estimation. Volumes 1 and 2. The Institution of Engineers, Australia.

Kuczera G., and Coombes P.J., (2001). A systems perspective of the urban water cycle: new insights, new opportunities. Stormwater Industry Association Regional Conference. Port Stephens. NSW.

Kuczera G., Williams B., Binning P., and Lambert M., (2000). An education WebSite for free water engineering software. , 3rd Int'l Hydrology and Water Resources Symp., Inst. Eng. Aust., Perth, 1048-1053.

Lloyd C., Troy P., and Schreiner S., (1992). For the public health. Longman Cheshire. Melbourne.

Maher W., Lawrence I., and Wade A., (1997). Drinking water quality. Australia: State of the Environment Technical Paper Series (inland waters). Department of Environment, Sport and territories. Canberra.

Mitchell, V.G., Mein R.G., and McMahon T.C., (1997). Evaluating the resource potential of stormwater and wastewater; an Australian perspective. Water Resources, 2(1),19-22.

Mobbs M., (1998). Sustainable house. Choice Books, Sydney.

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

Pacey A., and Cullis A., (1986). Rainwater harvesting. Intermediate Technology Publications. UK.

Schilling, W., and Mantoglou, A., (1999). Sustainable water management in an urban context, In: Drought management planning in water supply systems, Cabrera E., and Garcia-Serra J., (Eds), Kluwer Academic Publishers, 193-215.

Simmonds G., Hope V., Lewis G., Whitmore J., and Gao W., (2001). Contamination of potable roof collected rainwater in Auckland, New Zealand. Water resources. 35, 6. 1518-1524.

Taylor R., Sloan D., Cooper T., Morton B., and Hunter I., (1999). A waterborne outbreak of Salmonella Saintpaul. Central Public Health Unit, Rockhampton. Queensland.

Van Gelderen J., (1998). 'Hands on' approach to recycling stormwater in the landscape. The Environment Design Guide. The Royal Australian Institute of Architects. DES 19. February.

Yaziz M. I., Gunting H., Sapari N., and Ghazali A. W., (1989). Variations in rainwater quality from roof catchments. *Water Resources.* 23, 6. 761–765.

Biography

Peter Coombes MIE B.E. (Civil) (Hons), B. Survey (Hons). Dip. Eng. (Hons) is currently completing a PhD on the topic "Systems Implications of the Use of Water Sensitive Urban Design Source Control Measures" at the University of Newcastle. He has in excess of 20 years experience in the water resources industry and is the NSW Chairman of the Stormwater Industry Association. He has recently been appointed as a Post Doctoral Fellow on a research program to develop strategies for optimal source control in urban water cycle management with Associate Professor George Kuczera and Professor Jetse Kalma from the Department of Civil, Surveying and Environmental Engineering and Dr. Hugh Dunstan from the Department of Chemical and Biological Sciences.

Associate Professor George Kuczera is a senior lecturer in water resources engineering at the University of Newcastle.