Some examples of water recycling in Australian urban environments: a step towards environmental sustainability

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Abstract This paper discusses the concepts and results from two contrasting types of water recycling initiatives in Australia. The first type of initiative is a centralised scheme based on local authorities recycling sewage effluent and/or stormwater in urban areas. A new urban subdivision in Queensland (Springfield) is provided as an example of such a centralised scheme, with uses ranging from dual reticulation, to public space irrigation, to urban lakes. The importance of strong public consultation and partnership is stressed for scheme success. A second example of a centralised scheme is an upmarket subdivision in Adelaide, South Australia (Mawson Lakes), where stormwater and recycled effluent are designed to supply in excess of 70% of the community's total water requirement. Scheme success is highly probable because of the ready adoption of innovative water supply alternatives by South Australians. The other type of initiative operates at a household scale (Healthy Home) and demonstrates that reinventing old ideas using new technologies can allow urban households to become largely self reliant for their potable and non-potable water needs, at least in high rainfall coastal areas. However, the cost effectiveness of this self reliance will require a substantial change in the sharing of savings from deferred public infrastructure costs. We include for comparison an analysis by Coombes *et al*. for the Lower Hunter region which clearly demonstrates that adoption of water sensitive urban design features, such as rainwater tanks in new developments, is not only more cost effective than traditional infrastructure solutions, but also allows the deferral of new urban water supply dams by the order of decades. We conclude the paper with the observation that advances in incorporating externalities into water development economics, the "trickle down" effect of new distributed technologies, and the growing desire by urban communities to live within the capacity of their regional ecosystems will probably ensure that reforms in the urban water and wastewater cycles will pioneer the way to genuinely sustainable and liveable urban communities in the near future. In short, the Ecological Footprint of urban development will be substantially reduced.

Keywords Australian recycling projects; economic analysis; effluent quality; effluent reuse in urban areas; stormwater

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Introduction

There is increasing international interest in developing cities which are "safer, healthier, more liveable, equitable and productive" than our existing models. The concept has been termed Sustainable Cities (UN, 1996), and has evolved over the last eight years following the UN Earth Summit in Rio de Janeiro in 1992 where 179 nations adopted Agenda 21 sustainable development strategies and green plans. Local Agenda 21 are initiatives (by local authorities) to identify local environmental problems and remedy them – in other words, "thinking globally, but acting locally".

As invariably happens when society undergoes a major paradigm shift, near simultaneous eruption of ideas come from a variety of disciplines. One of the more influential paradigm busters were environmental economists Wackernagel and Rees (1996) who coined the term "Ecological Footprint", which is the area of arable land and aquatic ecosystem required for a society to maintain its standard of living, in terms of resources consumed and wastes assimilated. Using an urban metabolism accounting approach, Wackernagel and Rees (1996) calculated that about 8.4 ha of arable land was required to maintain the lifestyle of the average westerner, which is about five times larger than their "fair earth share". Clearly if western society were to implement the Brundtland Commission (1989) exhortation of raising the standard of living of all the worlds inhabitants to near western society standards, then another four worlds will be required.

Alternatively western society could reform itself so that it becomes more frugal in the use of natural resources, and mimic the cyclic metabolism of natural ecosystems. In effect, urban societies could realign their consumption to realistic needs, produce more of their own food and energy, and recycle much more of their wastes (O'Meara, 1999).

The water cycle is one of the more self evident examples of natural cyclical systems, but for the most part, cities treat this resource as a linear system of "take, make and waste". Rees (1996) is more strident in his criticism and states, "cities are dependent on a vast global hinterland of ecological landscapes; in ecological terms they are the human equivalent of cattle feedlots".

Water would seem to be one of the more obvious natural resources for society to reduce consumption and increase recycling. Sewage effluent for example, is a major water resource which is often used once and then discarded. Queensland processes nearly 340,000 ML of treated sewage effluent each year in 241 sewage treatment plants, with the vast majority discharged into rivers and estuaries (Bryant *et al.*, 1994). Approximately 10% (38,000 ML/yr) is used for beneficial purposes, and of the 27,400 ML/yr used for urban purposes, the vast majority is used for golf course irrigation (White, 2000). Considering that the population of the coastal strip of South East Queensland is projected to increase from 3 million to 6 million persons by 2049, and that effluent is the only water resource which increases with population, it seems eminently sensible to implement changes now which will reduce both our demand for new water impoundment, as well reduce the export of nutrients into our coastal waters.

In this paper we discuss the start of an 1.5 M$ water reuse innovation in urban Queensland where treated sewage effluent will be used in a new subdivision (Springfield) for public space and school ground irrigation, for dual reticulation in houses and for topping up urban lakes. We compare this with a less traditional urban reuse scheme in Adelaide where stormwater and recycled effluent will be stored and retrieved from saline aquifers to meet over 70% of the total water demand of a 3,400 allotment development at Mawson Lakes (Marks and Eddleston, 2000).

We contrast these suburb scale developments with preliminary water supply and effluent treatment results from a Healthy Home® in a Queensland beachside suburb, where the owner has built a water and energy efficient home that promotes human well being in a high density urban environment. In order to gain a perspective on the potential resource and monetary savings from this form of individual self reliance, we briefly review the recent analysis of Coombes *et al.* (2000) who scaled up the water sensitive urban design components of a 27 townhouse development at Fig Tree Place in Newcastle (Coombes *et al.*, 1999) to the whole of the Lower Hunter water supply district of almost half a million persons.

The Springfield project

The Springfield project links the state (Queensland) and local (Ipswich) governments with a land developer (Delfin) to implement acceptable reuse practices. Springfield is a 2,850 ha subdivision located between Brisbane and Ipswich with a projected population of 60,000 in 18,000 home sites by 2012. The components of the 1.5 M$ scheme involve (Table 1) a 500 kL/d tertiary disinfection plant achieving Title 22 standard effluent (i.e. 5 log reduction in viruses, 2 NTU and <2 TC/100 ml: California Dept. of Health Service, 1978) from a secondary treated effluent from Ipswich Water's Carol Park sewage treatment plant (other water quality targets are TN ≤ 5 mg/L TP ≤ 4 mg/L; SAR ≤ 7; EC ≤ 1.3 dS/m). Secondary treated effluent will be pumped 6 km through an existing pipeline into a 3 ML water reservoir where extended chlorine contact (CT ≥ 450 mg·min/L) will take place after suspended sediment is largely removed in a clarification – dual media filtration system at the base of the tower.

The treated effluent will then be reticulated through 5 km of pipe to irrigate road verges and median strip; public parks, pathways and bikeways; drainage and wildlife corridors, and school grounds, as well as topping up a 4 ha urban lake which will be used for non contact recreation, and possibly supplemental irrigation of surrounding parkland and a sporting field. Some of the disinfected water will be dual reticulated to 30 houses after passing through a further 4.5 kL/d microfiltration process, followed by UV disinfection and chlorination (Table 1). This further processing is required for protozoan removal, which is usually not effectively achieved using extended chlorination (Murray *et al.*, 1999). The dual reticulated water will be used for most non-potable household purposes (e.g. toilet flushing, garden irrigation, car washing etc.)

The eventual cost of the scheme is 1.5 M$. This includes the sediment removal – disinfection train and the reticulation infrastructure (630,000 $), the micro filtration and disinfection system (400,000 $), the school – ground irrigation system (227,000 $), the sporting field below ground irrigation system (93,000 $) and the disinfection of urban lake water if used for open space irrigation (100,000 $). This latter expense is particularly interesting from an regulatory view point as Title 22 treated water is the influent water!

The cost of the open space irrigation water is likely to be $<400/ML which is less than half the price of potable water from Ipswich Water. Because many of the new subdivisions in the Brisbane region occur on shallow soils with a dry sclerophyll forest cover, open space irrigation is important to “green up” the development to make it aesthetically pleasing to potential home owners.

The school irrigation project is seen as a particularly important demonstration project at a number of levels. Firstly because children are involved, public health aspects are uppermost and close consultation with the school community and the P & C organisation was essential to allay concerns. Secondly the ability to implement fundamental change in society environmental values comes largely from the social values and ethics that are taught in schools, especially primary schools. We see Springfield State School as a multifaceted role model for the construction and/or refurbishment of other schools in Queensland. This “early adoption” model is consistent with the Queensland Water Recycling Strategy Policy that public institutions lead by example in recycling wastewater (US.EPA, 2001).

The overall Springfield project is underpinned by a strong consultation process involving all levels of government (federal, state, municipal), especially the elected representatives, as well as the recipients of the renewed water (i.e. sporting clubs, school, community organisations). A full time community liaison/education officer has been attached to the

Table 1 Effluent reuse projects at Springfield, their corresponding treatment systems and required microbiological standards

Reuse option	Treatment	Microbiological STD
Sub surface irrigation of sports field	100 µm disc filter plus shock chlorination	≤ 10 FC/100 ml
Surface irrigation	100 µm disc filtration; flocculation; multimedia filtration; extended chlorination (CT ≥ 450 mg˙ min/L) (Title 22 treatment)	≤ 2 TC/100 ml NTU< 2
Dual reticulation	Title 22 followed by microfiltration; UV @ 30 mW sec/cm^2; and chlorination (CT ≥ 30 mg˙min/L)	≤ 1 TC/100 ml ≤ 2 virus/50 L ≤ 1 protozoan/50 L
Urban lake irrigation	Chlorination (CT ≥ 60 mg˙min/L)	≤ 10 FC/100 ml

project and (she) has been very active in shopping centre displays, articles in the local suburban paper, special newsletters as well as attending school and community meetings. If the prototype scheme proves to be an environmental, social and economic success, it is anticipated the scheme will be expanded into a 1,400 ML/yr urban project at Springfield. It is also likely that Delfin will use Springfield as a role model for their other urban developments in southeast Queensland.

Mawson Lakes

An alternative example of water sensitive urban design (WSUD) at a subdivision scale is the upmarket Mawson Lakes development near Adelaide where 3,400 home sites are located on 620 ha with 30% open space including 70 ha of lakes and waterways. The development is a partnership between developers Delfin and Lend Lease and the South Australian government. Using a combination of stormwater capture, wetland treatment and storage and effluent recycling, the dual reticulation subdivision is projected to reduce its demand on external potable water to ≤ 30% of its total annual requirement of 1,600 ML/yr (Marks and Eddleston, 2000). The recycled effluent will be treated to Class A disinfection standard. This requires low turbidity (≤ 2 NTU), low FC (<10 CFU/100 ml) and the essential absence of enteric pathogens: (≤ 1 virus/50 L).

The two water sources (treated stormwater and microfiltered, UV disinfected effluent) are combined and then chlorinated before distribution in the dual reticulation system. Because of the episodic nature of runoff, and the strong seasonal demand for (urban irrigation) water in Adelaide's Mediterranean climate (8 ML/d in winter, increasing to 150 ML/d in summer), some method of evening out the demand/supply discrepancies is required. Hence approximately 600 ML of stormwater will be captured each year, with the majority stored and retrieved from a 180 m deep saline aquifer underlying the site. This is termed Aquifer Storage and Recovery – ASR (Dillon *et al.*, 1999). Because of the reasonably even weekly generation of reclaimed effluent, the seasonal surplus of approximately 120 ML/yr will be stored in a shallower (120 m deep) saline aquifer. Overall, 500 ML of the total yearly demand of 1,600 ML is expected to be supplied from reclaimed effluent. The reclaimed water and stormwater will be used for toilet flushing and all outside uses except filling of swimming pools.

The overall cost of the blended recycled water is expected to vary between 0.80 to 1.15 $/kL depending on the fraction of headwork capital costs (10.5M$) which is recouped in allotment sales. In comparison, the price of normal potable water is 1.20 $/kL, demonstrating the economic advantage of adopting WSUD principles in new subdivisions.

Healthy Home®

Individual households represent the other end of the water reuse spectrum, and it is not uncommon in periurban areas for houses to have their own water supply (from rainwater tanks) and on-site sewage treatment and disposal systems. However, surveys undertaken in non sewered areas invariably report a high (≥ 50%) failure rate of aerobic treatment systems (Beavers *et al.*, 1999), and in some cases, actual discharge of greywater directly into street gutters (Jelliffe, 1994). It is therefore a courageous move by a local authority to allow a home owner to supply their own potable water and treat their own sewage in a densely settled urban area. Mobbs (1998) pioneered this concept with his Sustainable House in the inner Sydney suburb of Darlinghurst, and in this section we describe the Prosser's Healthy Home on a small (420 m^2) urban allotment on the Gold Coast, Queensland.

The Healthy Home® is a joint undertaking by the home owners, architect Dr Richard Hyde at the University of Queensland, and the Queensland Department of Natural Resources and Mines. The objective of the house was to use lightweight building materials with low embodied energy; low recurrent energy because of natural cooling achieved using a combination of insulation, breezeways, and thermal stack effects; recycled, plantation and reconstituted timber for construction; low outgassing coating including paint and floor coating; no PVC plumbing; a solar hot water system; a photovoltaic system linked to the power grid; rainwater for potable use, and a grey water treatment system for toilet flushing and garden irrigation.

The home layout is shown schematically in Figure 1 where 120 m^2 of the 167 m^2 roof area supplies roof runoff to a 22 kL concrete cistern installed under the low set house. First flush devices located on each down pipe ensure that the first 1 mm of roof runoff goes to waste. The rainwater is reticulated through the house using a 0.7 kW pump after first passing through a 20 µm filter and 40W UV disinfection system. The rainwater cistern is supplemented from town water supply, after passing through a backflow prevention device.

The greywater system is a recirculating sand filter contained within a partially buried 6 kL concrete tank. The tank compartments form a septic/surge tank, two pump wells and a 1.5 m^2 by 800 mm deep sand filter. The programmable flow controller *doses* the sand filter up to 96 times per day to maximise contact between the attached media growth and the percolating greywater (Tchobanoglous, 1999). When the water level in the (second) pump well goes "high", about 20% of the treated greywater is discharged to waste (or to another storage), to maintain hydraulic balance, with the remainder recycled through the system. Under the Queensland Water Supply and Sewage Act (1949), greywater reuse is prohibited in sewered areas. Permission to install the greywater system was given by the Gold Coast City Council on the proviso that all grey water from the bathrooms and laundry was discharged to sewer. All other liquid waste from the house (toilets and kitchen) is discharged to sewer. The potable and greywater systems are intensively monitored to measure flow rate and volume using 16 pulse generating water meters; the rainfall and cistern water level are measured with a tipping bucket rain gauge and pressure transducer respectively; the greywater system is regularly connected to an ISCO auto water sampler to collect pump-out samples over a 24 hour period. These sand filtered samples, along with septic tank samples, are analysed within 24 hours for a suite of chemical and microbiological characteristics. Less frequent samples of the tank water have been taken from the cistern and taps for microbiological and chemical analysis.

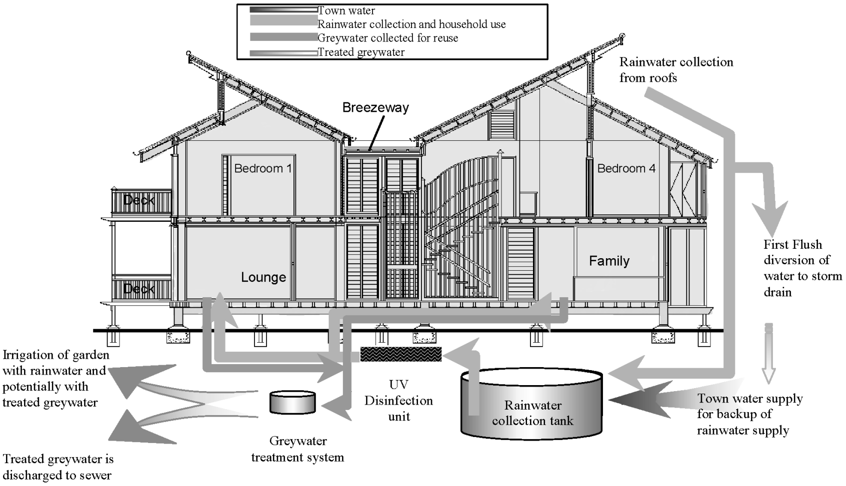

Figure 1 Schematic of the rainwater and grey water systems in the Healthy Home

Supply and demand results

During the 24 months of water monitoring over 2000 and 2001, the Healthy Home consumed 229 kL/yr of water (627 L/d) compared with an average Gold Coast detached household consumption of 297 kL/yr (averaged over 68,200 residences – Gold Coast Water) suggesting that the Healthy Home residents (two adults and three children) are relatively frugal in their per capita water consumption. Both 2000 and 2001 were years of well below average rainfall on the Gold Coast (1,460 mm/y) with values of 1,030 mm and 1,180 mm, corresponding to the 15 percentile and 26 percentile rainfall years respectively. Consequently rainwater supplied only 36% of the total water consumption by the Healthy Home over the two years. In an average rainfall year, this level of independence is expected to be considerably more, in the order of 65%. The partitioning of water use in the Healthy Home with the majority (34%) being used in the bathroom, followed by toilet flushing (20%) and outside use (20%) is shown in Figure 2. The bathroom consumption is unlikely to be reduced as a low flow shower rose (9 L/min) and 3/6 L dual flush toilet are already fitted, whilst the outside use is much smaller than accepted values (40–50%) from other capital city studies in Australia (e.g. Coghlan and Higgs, 2000; Jeppesen and Solley, 1994). The low outside consumption is a function of the small block size (420 m^2), the permaculture garden, and the installation of simple soil water monitors to schedule and terminate irrigation.

Approximately 40%, or 92 m^3/yr of total water use (toilets/external), could be replaced by greywater treated to an appropriate standard (Figure 2). This idea is explored in more detail in Table 2 showing the virtual water[1] balance for the combined years (2000 and 2001) where it is assumed that all toilet flushing water (91 kL) is sourced from treated greywater, with 50% of the balance of greywater (58 kL) used for garden irrigation. When combined with rainwater (165 kL), the self sufficiency of the Healthy Home could increase to nearly 70% (314 kL) of the 458 kL consumed in 2000 and 2001. In an average rainfall year, the demand on mains water could reduce to near zero as using 74 kL/yr of rainwater twice (the second time as greywater) comes close to cancelling out the need for importing the 105 kL/yr of mains water suggested by Figure 3.

Generalising these results for the long term (or for different locations, roof areas, tank volumes etc.) require water balance modelling. An example is shown in Figure 3 using the results from a daily time step water balance simulation using 110 years of rainfall record; 120 m^2 or 167 m^2 (total house and carport) roof area, an 80% rainfall catch efficiency (Cunliffe, 1998) and an average daily use of 627 L/d from a 22,000 L rainwater tank. For the larger roof area (167 m^2) approximately 77 kL of town water will be required in an average year, increasing to 105 kL for 120 m^2 roof area (as currently connected at the Healthy Home). These values will reduce in above average rainfall years and increase in below

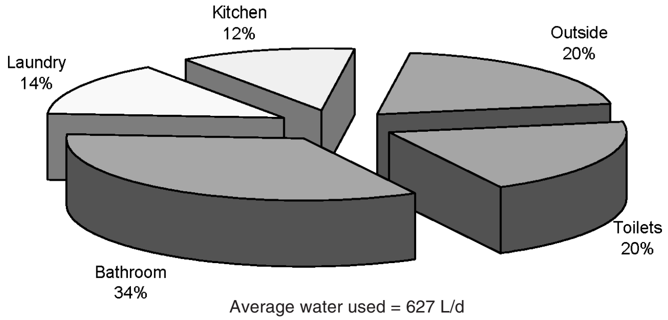

Figure 2 Partitioning of water use in the Healthy Home in 2000 and 2001

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[1] (Current Queensland Government regulation prohibits the reuse of greywater in sewered areas.)

Table 2 Virtual water balance of the healthy home for the combined years of 2000 and 2001

Water types	**Volume (m^3)**
Greywater treated	207
Toilet water use	91
Greywater available for irrigation	116
Assume 50% availability	58
Potential greywater use	149
Rainwater used	165
Potential rain + greywater use	314
Total water use	458
Rain + greywater = 68% of total water use of 458 kL	

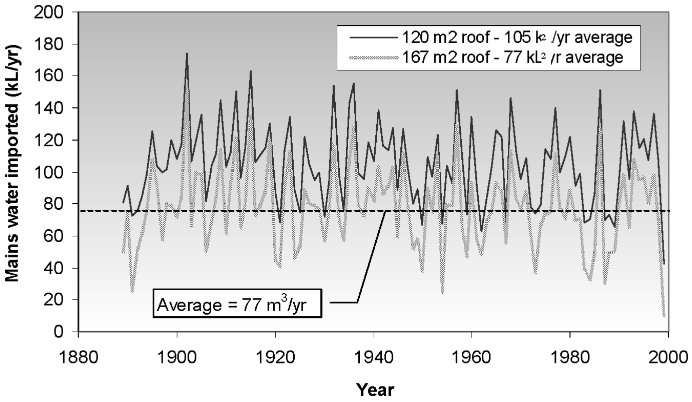

Figure 3 Predicted annual mains water required for two different roof areas for the Healthy Home using 110 years of daily rainfall records

average rainfall years. Taken overall, these results suggest that the average (detached) household on the Gold Coast could reduce their demand on town water supply from 300 kL/yr to about 100 kL/yr by installing a 20 m? rainwater cistern.

To give a sense of perspective to these savings, if Gold Coast residents could reduce their consumption by 25% (currently 60,000 ML/yr is supplied to residential and commercial customers) the need to raise the level of the main water supply impoundment, the Hinze Dam, can be postponed by at least 25 years with a deferred expenditure of 80 M$. It could reasonably be argued that some of this saving could be redirected towards water efficient housing as the $ 5,500 greywater system at the Healthy Home has an infinite pay back period, and the 2,600 $ rainwater system has a 74 yr payback period, assuming town water is costed at 1.10 $/$m^3$.

An alternative method of estimating water savings is to compare projected population growth with/without rainwater tanks. The Dept. of Local Government and Planning (2001) predicts a population growth of 214,000 persons over the next 20 years in the Gold Coast statistical area. Assuming an average occupancy rate of 2.5 persons per house, this is equivalent to 85,600 new homes, or 4,280 new homes/yr (on average). Residential water demand is therefore expected to grow at an average rate of 1,270 ML/yr with a total increase of 25,425 ML/yr by 2021 assuming no new water savings or initiatives are implemented. However, if rainwater tanks are mandated for all new houses, the increase in mains water demand will be reduced to 8,990 ML/yr (105 kL × 85,600 houses) which is well within the safe yield reserve of the 30,000 ML/yr from the raw water supply storages. The actual spare capacity in the system is 26,100 ML/yr after leakages in the reticulation system are accounted for.

Effluent quality

Sewerage regulation in Queensland forbid the use of greywater in sewered areas, primarily because of health, contamination and nuisance risks observed historically in non sewered urban areas. Consequently the regular monitoring of the treated greywater at the Healthy Home was primarily intended to provide quantitative data on the quality of greywater that could be consistently achieved using recirculating sand filter technology (see Tchobanoglous, 1999 for the advantages of recirculating sand filters). The microbiological and chemical results from a year of fortnightly monitoring are shown in Table 3. The median BOD, SS, turbidity and faecal coliform values easily meet the Dept. of Natural Resources (DNR) (1999) standard for unrestricted reuse. However FC on occasions did not achieve the 10 CFU/100 ml standard, despite the retrofitting of an 80W UV disinfection system in December 2000. We are unsure of the reasons for this behaviour (considering the consistently low turbidity) but note that from May 2001 onward, faecal coliform levels have been ≤10 CFU/100 ml (data not shown). Salinity (0.4 dS/m) and sodicity (SAR of 2) of the greywater are at levels that present no hazard for amenity irrigation (DNR, 1999) despite the concerns often expressed about the levels of these parameters in greywater (e.g. Patterson, 2001). Similarly N and P levels are very low compared with other greywater studies (Jefferson *et al*., 2001) presumably because kitchen waste in the Healthy Home was diverted to the sewer system. Taken overall, a year of regular monitoring has established that a recirculating sand filter with a disinfection process can consistently produce a high clarity, low colour, microbiologically safe effluent that can be used for toilet flushing and above ground garden irrigation.

Potable water

There is a general reluctance by health authorities in Australia to endorse rainwater tanks for potable uses in urban areas because of concern from contaminants washing off the roof. We anticipated this health risk problem could be solved at the Healthy Home by the installation of first flush devices, which diverted the first millimetre of roof run off to waste. Despite the successful operation of first flush devices in the Healthy Home, there were frequent intervals when faecal and total coliform levels in the rainwater tank exceeded the NHMRC drinking water standard (Australian Drinking Water Guidelines, 1996) of zero CFU/100 ml for both organisms, with peak values as high as 500 CFU/100 ml occurring after heavy rainfall events. Similar high concentrations of FC have been reported by Coombes *et al*. (2000) for rainwater tanks in cluster housing at Newcastle. But in both cases, these levels are unlikely to be associated with human pathogenic organisms for which faecal coliform is an indicator (Cunliffe, 1998). Nonetheless after a 40 W Trojan UV system was fitted to the rainwater tank at the Healthy Home in August 2001, all subsequent

Table 3 Water quality of greywater at the healthy home before and after treatment

Parameter	**Unit**	**Raw greywater *n* = 23**			**Sand filtered greywater (*n* = 24)**			**DNR (1999) irrigation guidelines**
		Median	**Min**	**Max**	**Median**	**Min**	**Max**	
BOD_5	mg/L	74	48	170	6	3	60	(10
SS	mg/L	52	18	370	2.7	2	49	(10
Turbidity	NTU	–	–	–	1.4	0.7	17	<2
FC	CFU/100 ml	100	0	19,000	1	0	300	10
TC	CFU/100 ml	100,000	300	650,000	18	0	15,000	–
SAR		–	–	–	1.9	0.7	4.9	–
TN	mg/L	5.1	1.6	11.0	3.0	0	7.4	–
TP	mg/L	0.6	0.1	12.0	0.7	0.1	4.1	–
EC	mS/cm	–	–	–	0.4	0	1.3	–

fortnightly samplings returned zero values for faecal and TC. Moreover water clarity was high (true colour ≤ 5 Hazen units) and the heavy metals (Zn, Cr, Cu, Cd) levels were all below NHMRC (1996) guideline limits (e.g. ≤ 0.02 mg/L for cadmium; ≤ 0.05 mg/L for chromium; < 2 mg/L for copper).

Economic analysis of water sensitive urban design

Coombes *et al*. (2000) recently described an economic analysis of rainwater tanks where they extrapolated the water saving results from a 27 townhouse study at Fig Tree Place, Newcastle, to the whole of the Lower Hunter region in New South Wales, which services 455,000 people. The cluster housing project uses rainwater tanks to store roof runoff for hot water systems and toilet flushing, and detention basins and soakage trenches to reduce stormwater runoff volumes and peak flows (Coombes *et al*., 1999). The stormwater is stored in a shallow aquifer and used for garden irrigation (and bus washing). Using sophisticated demographic statistics; costs and consumption data from Fig Tree Place, and a statistical model for year to year variation in household water consumption, Coombes *et al*. (2000) projected that 200 M$ in headwork costs could be deferred from 2040 to 2075 if all new dwellings (0.9%/yr growth rate assumed) were fitted with rainwater tanks (10 kL) and existing homes were retrofitted at a rate of 2% a year.

The economic implication of this deferral was assessed using a present equivalent analysis (Smith 1979) which identifies the capital investment required in the year 2000 to finance the various scenarios over the next 100 years. For the base case (i.e. conventional water supply and stormwater infrastructure) 17 M$ would be required today to fund the 0.9%/yr growth rate (Table 4). However, if all new growth adopted Water Sensitive Urban Design features (WSUD) and rainwater tanks were retrofitted to existing homes at rates varying from 0.25% to 3% a year, a wide range of capital investment is required. For example for new growth and retrofitting up to 0.9%, capital investment is not required. In fact, additional funds are generated (i.e. – 6 M$ for the "new growth plus 0.9%" retrofit case). However once the retrofitting rate exceeded 0.9%/yr, the scheme was not financially viable (e.g. +62 M$) when compared to the base scenario (+17 M$).

Accepting that the assumptions used by Coombes *et al*.(2000) are valid, their analysis demonstrates WSUD for biophysical and economic source control, and installation of rainwater tanks to all new housing appear to be economically more attractive than traditional water supply and stormwater infrastructure. If the environmental costs (externalities) associated with delaying the construction of dams were factored in, the savings would be even higher.

Table 4 Present equivalent analysis of the capital investment required today to fund a 0.9%/yr growth rate in the Lower Hunter using conventional water supply and stormwater systems, and water sensitive urban design alternatives which include retrofitting rainwater tanks to existing dwellings (Coombes *et al*., 2000)

Scenario	Investment required (M$)
Conventional infrastructure for new growth	+17
WSUD[1] for new growth (N)	–50
N + R/F[2] @ 0.25%/yr	–33
N + R/F @ 0.5%/yr	–23
N + R/F @ 0.75%/yr	–13
N + R/F @ 0.9%/yr	–6
N + R/F @ 2.0%/yr	+62
N + R/F @ 3.0%/yr	+102

[1] WSUD= rainwater tanks, stormwater infiltration and detention basins
[2] R/F = Retrofit existing dwellings with rainwater tanks

Conclusions

This paper has demonstrated that the principles of Water Sensitive Urban Design can be applied at both subdivision level and individual householder level. Although the Springfield project is just commencing, the value of early community consultation and participation in encouraging ownership and deflecting the community outrage factor, is very evident. There has been strong demand by the incoming residents for dual reticulation as recycled water charges will be less than half that of potable water costs. A similar *Natural Capitalism* response (Hawken *et al*., 1999) is a major reason for Delfin's support of the recycling project, where "green" subdivisions translate into a sales advantage.

Mawson Lakes is a more courageous move by private urban developers to incorporate innovative water capture, storage and supply of stormwater and recycled effluent throughout the whole of an upmarket subdivision. As such, it is more innovative and holistic than Springfield, and will probably succeed because it taps into the more liberal attitudes of the community and regulatory authorities in Adelaide who appear more willing to accept "risks", probably because of the low reliability/quality of their traditional potable water source (Murray river).

The Healthy Home data suggests that in high rainfall coastal areas of Australia, small urban allotments can become largely "independent" of reticulated public utilities, but not necessarily at cost effective prices. This will require a substantial change in the pricing policy of water and sewerage supply, as well as a sharing with local authorities of the savings from deferring new infrastructure investment. The analysis by Coombes *et al*. (2000) clearly demonstrates this sharing of costs/savings is economically viable for new developments, but the rigorous incorporation of externalities into the economic debate has yet to be convincingly made.

We believe that innovations in water and sewerage systems can pioneer the changes in urban metabolism that are required to "change cities into sustainable systems in terms of their natural resource consumption and waste production, whilst simultaneously improving their liveability so that they can better fit within the capacities of local and regional ecosystems" (Newman and Kenworthy, 1999).

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