

Integrating recycled water into urban water supply solutions

J.M. Anderson

*NSW Department of Commerce, McKell Building L13, 2-24 Rawson Place, Sydney, NSW 2000, Australia
Tel. +61 (2) 9372-7811; Fax: +61 (2) 9372-7822; email: john.anderson@commerce.nsw.gov.au*

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Abstract

In many parts of the world, growing demands for water are beginning to outstrip available supplies, and there is competition among users for available water. Sydney, the capital city of the state of New South Wales in Australia, is an example where urban water demands have reached the capacity of the existing water supply system. The New South Wales state government has introduced new water sharing rules that require increased water allocations for environmental flows to maintain river health, particularly in low flow periods. The government is introducing new planning measures to achieve 40% water savings in new houses compared to the current Sydney baseline. In the case of Sydney, the government has recently released a Metropolitan Water Plan that will enable Sydney to meet environmental flow requirements and cater to growth for the next 30 years. The new planning requirements significantly increase the opportunities to integrate water recycling into urban water supply systems to increase available supplies and minimise environmental impact. Amendment of the NSW guidelines for urban and residential use of recycled water to allow laundry use would bring down the cost of residential water recycling systems. An example is given as to how a water recycling network could be integrated into the new development areas in Sydney to improve drought security and the environmental outcome by using recycled water for multiple uses including urban, agricultural and environmental. The capital cost, water pricing and energy use implications of such a network are discussed.

Keywords: Integrated water planning; Water recycling; Water pricing

1. Introduction

In many parts of the world, growing demands for water are beginning to outstrip available supplies, and there is competition among users for the available water. Sydney, capital city of the state of New South Wales in Australia, is an

example where urban water demands have reached the capacity of the existing water supply system.

The Hawkesbury–Nepean River system is the principal water source for the city of Sydney. The Hawkesbury–Nepean River basin has a catchment

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area of 22,000 km², an average annual rainfall of 890 mm/y, and an average annual discharge of about 3,000 Mm³/y. Like all Australian catchments, the rainfall and streamflow are highly variable. The Hawkesbury enters the Pacific Ocean about 30 km north of Sydney on the east coast of Australia.

Since the Nepean River was first tapped for Sydney's water supply in 1886, the population of Sydney has grown from less than 1 million to more than 4 million. The population is expected to grow by another million over the next 20 years. The major Sydney water storages command about half of the Hawkesbury–Nepean catchment and have average annual inflows of about 1,600 Mm³. In addition, there is a diversion system to pump water from the Shoalhaven River, 160 km south of Sydney. The current Sydney water supply system has a yield of about 600 Mm³/y. Water consumption in 2002–2003 reached 635 Mm³/y. New South Wales has experienced a sequence of severe droughts since 1990, and storage levels are currently below 45%.

In the 20th century the Hawkesbury–Nepean River system was “loved” almost to ruin as a result of land use changes and urbanisation, water diversions and reduced flows. The river has also been affected by sand and gravel extraction, loss of riparian vegetation, rubbish dumping and pollution. The impact is most clearly manifested in declining water quality with the growth of aquatic weeds, blue-green algae outbreaks in the lower reaches, invasion of exotic plants and loss of biodiversity.

2. Water reforms

Since 1995 the current New South Wales state government has embarked on a series of major water reforms with the aim of improving the health of New South Wales rivers.

1. **Healthy Rivers Commission:** This was appointed in 1995 to conduct inquiries and make

recommendations to improve the health of New South Wales rivers. The commission's 1998 inquiry into the Hawkesbury–Nepean system made numerous recommendations to improve river health.

2. **The Sydney Catchment Authority:** this was created in 1999 with a charter to improve the protection of the Sydney water catchments. The government also introduced new planning controls to manage those developments in the catchments which might have an impact on water quality.

3. **Water Management Act:** The Water Act 1912 has been replaced with a new NSW Water Management Act 2000. Key elements of the new act are water management for sustainable use, a new water access framework to prevent over-allocation, and water sharing plans to share available water between users and the environment.

4. **Agency reform:** A new Department of Infrastructure, Planning and Natural Resources was created in 2003 with responsibility for water resource management and reforms and the implementation of water sharing plans. Catchment management authorities were created for each of the 35 major river basins in New South Wales.

5. **Hawkesbury–Nepean River Management Forum:** This group was appointed in 2001 to recommend environmental flows and to advise on integrated water management for Sydney. After extensive studies, the Forum has recommended interim minimum environmental flows below the Nepean storage of all inflows up to the 80th percentile flow (20% “transparency”) plus a minimum of 20% of flows in excess of the 80th percentile flow (20% “translucency”); and below Warragamba, all inflows up to the 95th percentile flow (5% “transparency”) plus a minimum of 20% of flows in excess of the 95th percentile flow (20% “translucency”). In addition some specific contingency flows will be allowed for river flushing/scouring, fish spawning and aquatic weed control. The effect of the interim flows will be monitored with a view to deciding on a final

environmental flow regime for the Hawkesbury River by 2015. The interim environmental flow requirements are reported to reduce the yield of the existing water supply system by about 15% to 20%.

3. NSW water recycling initiatives

Water recycling initiatives in New South Wales play an important part in facilitating the development of water recycling in Australia. Important initiatives include:

1. 1982 Task Force: Following the recommendations of a 1982 Task Force, the NSW government established the NSW Recycled Water Coordination Committee in 1984. The Committee played a valuable role in facilitating the 1987 NSW guidelines, supporting important R&D projects such as the Wagga tree plantation project, and promoting reuse through the NSW Recycled Water Seminars series, which brought leading world experts in water recycling to Australia.

2. NSW Guidelines for Urban and Residential Use of Reclaimed Water: The NSW Recycled Water Coordination Committee published Australia's first residential reuse guidelines in 1993 following an 18-month trial at Shoalhaven Heads.

3. Rouse Hill: The dual-reticulation residential water recycling scheme at Rouse Hill was the first of its type in Australia, supplying recycled water for garden watering and toilet flushing in residential houses. The scheme now supplies more than 15,000 houses. The government has recently announced extension to serve a further 10,000 houses.

4. Homebush Bay: The dual-reticulation water recycling scheme at Homebush Bay has extended the urban water recycling concept, incorporating both stormwater and recycled water, supplying residential housing, major sporting facilities and parklands.

5. Eraring: The dual-membrane water recycling system installed at the Eraring power station

near Newcastle in 1995 was one of the first of its kind in the world. It supplies up to 4 ML/d of high-purity recycled water as boiler-feed make-up water.

4. Metropolitan Water Plan

A new Sydney Metropolitan Water Plan was announced during National Water Week in October 2004 [1]. The proposed measures are expected to free up sufficient water to meet environmental flow requirements in the Hawkesbury–Nepean system and to provide for growth in demand over the next 30 years. The Plan incorporates both demand-side and supply-side measures.

4.1. Demand-side measures

BASIX: The government has introduced a new Building Sustainability Index, known by the acronym BASIX [2]). Under the BASIX provisions, all new houses in Sydney are required to achieve a 40% reduction in water use compared to the current Sydney average as a condition of development approval from 1 July 2004. The BASIX development approval scheme was extended to all other local government areas in New South Wales from 1 July 2005. The BASIX requirements effectively make the installation of water-efficient appliances and fittings mandatory. They also strongly encourage rainwater collection or recycled water systems to meet garden water needs. Further details of the BASIX scheme can be found on the DIPNR website.

Water efficiency plans: Major commercial, industrial, government and local government users are required to prepare water efficiency plans by March 2006 and to implement water efficiency measures by September 2007. The government is making available a Demand Management Fund to support capital investment in water efficiency initiatives.

Water efficiency labelling: In 2005 the government began requiring manufacturers and retailers to display a label showing the level of water efficiency on appliances such as toilets, showerheads, clothes washers and dishwashers. The government and industry associations also are introducing a “SmartWater Mark” labelling scheme for garden appliances and garden plants. Toilets that are not water efficient are being removed from sale as of 2005.

Existing households: The government will continue to support householders who want to install water-efficient devices in their homes. The current subsidised household water audit program will continue with householders making a \$22 contribution to the cost of the water audit and retrofitting of water-efficient fittings. The current rainwater tank rebate program is extended until July 2008.

Water education: Building on the success of current water reduction programs, the government will implement a new water education program for New South Wales to maintain and increase community awareness of the need for water conservation. The “Water Wise on the Farm” program continues to improve agricultural water efficiency.

Pricing: Sydney currently has a two-part tariff with a fixed charge and a volumetric charge for all water used. The government is currently considering recommendations from the Independent Pricing and Regulatory Tribunal that outline a new tariff structure where households will pay a higher price for water use above a reasonable volume.

Leakage reduction: Sydney Water will undertake a further extensive program of main renewal and leakage reduction to reduce system losses.

4.2. Supply-side measures

Apart from water recycling, a number of supply-side measures are proposed as part of the Metropolitan Water Strategy to improve the

capacity and security of the existing water supply headworks.

Deep storage: It is proposed to provide access to deep storage below the current minimum operating levels in the water supply storages to provide a small increase in drought security (about 30 Mm³/y yield). This contingency will be activated only rarely during extreme drought events.

Shoalhaven transfers: It is proposed to alter the current pumping rules for transfer of water from the Shoalhaven River to Sydney to increase the amount of water transferred during wet periods. Consideration is also being given to some increases in the capacity of parts of the transfer system. There is potential to increase system yield by between 60 Mm³/y and 110 Mm³/y, depending on the extent of works undertaken.

Groundwater: There are some groundwater aquifers within a reasonable distance of Sydney. Further investigations will be undertaken as a drought contingency measure.

Desalination: Sydney Water will undertake a detailed evaluation of desalination as a contingency option to ensure that, if the current drought continues beyond another 2 years, a desalination plant could be constructed quickly if needed.

5. Integrating recycled water into urban water supply solutions

Sydney currently reuses about 14 Mm³/y of recycled water and expects to increase this to 22 Mm³/y in the near future through planned projects. Current projects include reuse for major industrial needs and residential reuse for garden watering and toilet flushing in new development areas.

As part of the Metropolitan Water Plan, the government will undertake detailed evaluation of water recycling options in Sydney. One option is to use recycled water from the western treatment plants which discharge to the Hawkesbury–

Nepean Rivers to supply new greenfield residential development areas, agricultural uses, and with appropriate nutrient removal, environmental flows below the storages. As well as reducing the demand on drinking water supplies, this proposal has the potential to reduce stress on urban streams by capturing western Sydney treatment plant discharge for beneficial reuse. This recycling option is potentially an important part of the initiatives to restore the health of the Hawkesbury–Nepean River system and its tributary streams.

5.1. Residential reuse in new release areas

For this study it was assumed that all new release areas in Western Sydney will have third-pipe recycled water reticulation systems to supply recycled water for residential garden watering, toilet flushing and laundry use. Recycled water would also be supplied for appropriate commercial uses and watering of public open space areas (Table 1).

5.2. Projected recycled water needs (Table 2)

The following new residential water, wastewater and recycled water demand assumptions were made:

- Average 450 m² lot size, subdivision density 16 lots/ha including roads and footpaths.
- Gross development density: 1200 lots/km² including non-residential and public open space areas.
- BASIX indoors with 3A-rated indoor appliances and fittings, average three persons per dwelling.

- Baseline garden water demands with average annual rainfall of 800 mm/y.
- The NSW residential reuse guidelines will be modified to permit laundry use of recycled water.
- Single residential house demands kL/a/house: Toilet 21.9, Laundry 27.7, Other Indoor 66.6 Garden 71.9, Pools 10.3
Total 198.4, Potable 76.9, Recycled 121.5.
Overall residential reuse system demands = residential use + 10% for commercial and open space. Total recycled water demands = 133.7 kL/y/house.
- Average dry weather wastewater flows including infiltration = 136 kL/y/house.

The following system assumptions were used for analysis of the residential reuse systems:

- Service reservoirs at about 4 km spacing.
- Delivery rate from STPs to reservoirs = 85% of drought year peak day.
- Reservoir capacity = 120% of drought year peak day.

The cost of third-pipe recycled water systems has been reduced by the adoption of smaller lot sizes in new subdivisions. The estimated costs are: service reservoirs and distribution mains \$690/house, and local reticulation and house services \$1950/house. Provision of a third-pipe recycled water system is estimated to reduce potable water reticulation costs by about \$640/house [3].

5.3. Agricultural reuse

The Department of Primary Industries (Agriculture) has previously estimated total rural water

Table 1
Assumed population in new release areas

Area	Lots	Population
Northwest sector	57,000	171,000
Southwest sector	55,600	166,800
Total	112,600	337,800

Table 2
Projected urban and residential recycled water demands

Area	Average year, Mm ³ /y	Drought year, Mm ³ /y
Northwest sector	6.9	8.7
Southwest sector	6.7	8.5
Total	13.6	17.1

use in Western Sydney to be on the order of 108 Mm³/y. The estimation is based on authorised areas and maximum irrigation rates. A significant proportion of rural water is supplied from farm dams and local creeks rather than pumping from the Hawkesbury and Nepean rivers. Also, in practice, not all potential irrigation demands can be supplied in dry years, while in wet years irrigation demands are lower. The amount of rural water use which might be replaced with recycled water is probably less than 50 Mm³/y. There may be some decline in rural water use as Western Sydney becomes more urbanised.

Previous agricultural reuse studies have identified the potential to supply up to 8.6 Mm³/y of recycled water to 1460 ha in the Richmond area. There is also potential to supply a further 5.6 Mm³/y to rural users along the river between Regentville and Richmond and some commercial and open space uses in and around Penrith. Previous studies have also identified potential to supply 1.3 Mm³/y of recycled water to 460 ha in the Dural area and 6.6 Mm³/y of recycled water to 1140 ha in the Camden area (Table 3).

The following system assumptions have been used for analysis of the rural reuse systems:

- Bulk supply from treatment plants = 1.5 × average daily demand.
- Bulk storage = 50 days storage at average daily demand.
- Distribution pipelines = 2.32 × average daily demand.
- On-farm storage for peak irrigation demands = 7 days at average daily demand.

Table 3
Projected agricultural recycled water demands

Area	Average year, Mm ³ /y	Drought year, Mm ³ /y
Northwest sector	15.7	22.1
Southwest sector	6.6	9.3
Total	22.5	31.4

5.4. Return flows

If some of the environmental flow needs below the Sydney storages are met with return flows of recycled water, then an equal amount of storage inflows can be retained in storage, giving extra water supply system yield.

The environmental flow requirements in the Nepean River below the Warragamba dam include the 95th percentile environmental flow requirements of 42.3 ML/d plus translucent flows of 20% of flows in excess of the 95th percentile flow. Potentially 68 ML/d of recycled water could be supplied from the St Marys and Quakers Hill treatment plant flow to provide return flows in the Nepean below Warragamba.

Environmental flow requirements in the Upper Nepean system include 80th percentile transparent environmental flow requirements of 60.3 ML/d at Pheasants Nest weir and 20.3 ML/d at Broughtons Pass weir plus translucent flows of 20% of flows in excess of the transparent flows. Potentially 54 ML/d could be supplied from the Liverpool and Glenfield treatment plants.

Table 4 shows the estimated average annual return flows based on flows available from the designated treatment plants. The second column shows the amount of recycled water used if return is not permitted to exceed 50% of the required environmental flow. The third column shows the amount of recycled water used if return flows provide 100% of environmental flows. In prac-

Table 4
Projected return flow recycled water demands

Warragamba flows	50% of flow, Mm ³ /y	100% of flow, Mm ³ /y
Northwest sector, 68 ML/d	21.1	23.6
Southwest sector, 54 ML/d	10.9	15.1
Total	32.0	38.7
Warragamba + Nepean flows, 122 ML/d		
Total	37.6	41.6

tice, the amount of recycled water available for return flows will be higher in the winter months but lower in summer months because of the other reuse demands on the system.

The following system assumptions were used for the return flow systems:

- All the inland treatment plants have tertiary filtration sufficient to supply residential reuse-grade recycled water.
- Return flows will normally be limited to a maximum of 50% of the environmental flow requirement in dry weather.
- Return flows will receive additional treatment using reverse osmosis membrane filtration or equivalent to reduce nutrients to minimum practical levels. A brine disposal pipeline will be constructed to transfer saline RO reject water to Malabar or some other suitable place for discharge to salt water.

5.5. Total demands and reuse

Total projected recycled water demands on the water recycling network in 2021 are shown in Table 5.

Table 5
Projected total recycled water demands in 2021

Area	Average year, Mm ³ /y	Drought year, Mm ³ /y
Residential reuse	13.6	17.7
Agricultural reuse	22.5	31.4
Return flows	37.6	27.0
Total	75.7	75.1

Fig. 1 shows the results of a monthly simulation of recycled water network operation over a 100-y period from historical records. Residential and agricultural reuse demands were varied seasonally, taking into account variations in rainfall and evaporation in wet and dry years. Return flows were varied to match natural flow patterns, taking into account the variations in natural streamflows before diversions. On average annual basis, the recycled water network would potentially reuse about 90% of the available western Sydney recycled water flows for beneficial purposes. The recycled water network would potentially use 100% of available daily flows in dry weather.

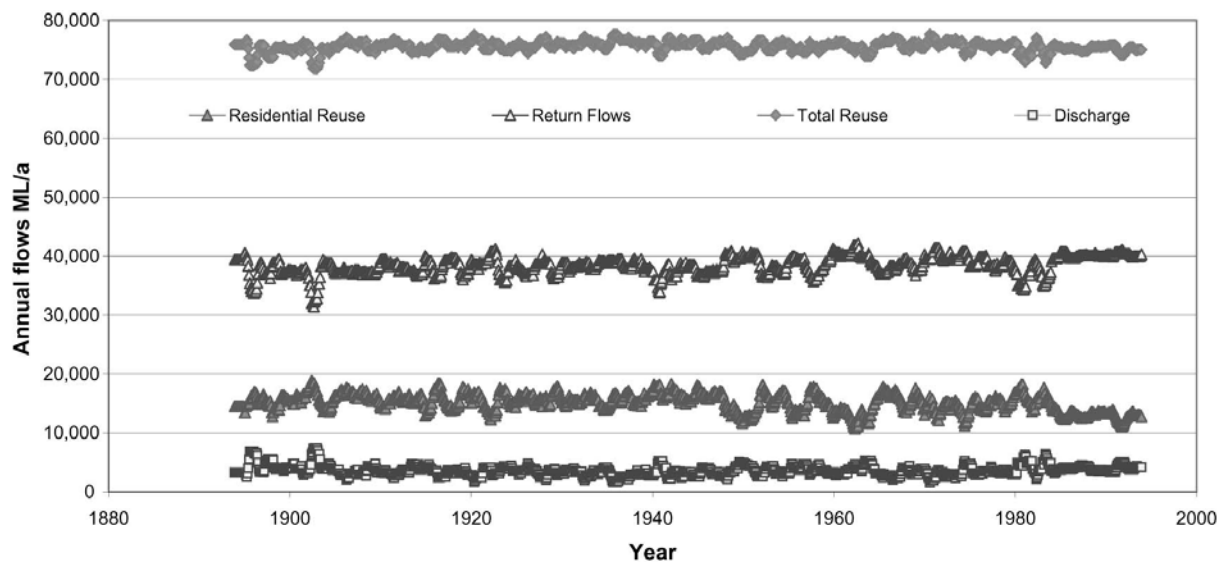


Fig. 1. Water recycling network, monthly simulation. Western Sydney water recycling 79.3 Mm³/y flow.

6. Discussion

6.1. Economic assessment

An economic analysis of recycled water network options was made assuming agricultural reuse benefits of \$230/ML of recycled water supplied and valuing increases in Sydney's potable water supply annual capacity through return flows or recycled water substitution at \$0.80/kL (\$800/ML) for extra water available at Prospect.

Preliminary estimates put the capital cost of the recycled water network at between \$563M and \$675M. Considerable cost savings occur through the sharing of the major recycled water transfer systems between the residential, agricultural and return flow reuse systems and through flow balancing to meet recycled water peaks. The net present value of capital and operating costs are estimated to be in the range \$560M to \$650M vs. the estimated net benefits of \$928M at a 7% discount rate. The rate of return on investment is estimated to be greater than 13% and exceeds the target rate of return for public investment in water and sewerage works across a wide range of assumptions about costs and benefits.

6.2. Network advantages

Conjunctive use of recycled water for residential, agricultural and return flows through an integrated recycled water network provides a number of advantages and cost savings.

- In drought years, residential and agricultural reuse demands will be higher but environmental flow needs and return flows will be lower, allowing reallocation of return flows to supply more recycled water for residential and agricultural uses.
- In peak summer demand periods, return flows can be reduced and reallocated to meet peak residential reuse demands without the need for extra delivery mains, and avoiding the need

for potable water top-up that currently occurs in the Rouse Hill system.

- In winter and wet weather periods, recycled water flows would exceed network demands necessitating some discharges. In the south-west sector, discharges to Hawkebury–Nepean could be minimised by reversing flows to deliver flows from Bringelly to Glenfield and Liverpool for discharge through the existing coastal system. In the northwest sector there would be the possibility of using the agricultural reuse network to discharge surplus northwest sector flows to the Hawkesbury below Windsor.
- If effluent discharges to the Hawkesbury–Nepean River system upstream of Windsor are minimised through beneficial recycled water use and management of discharges, there may be potential to reduce environmental flows requirements and increase drinking water allocations.

6.3. Energy use

Table 6 compares energy use for the recycled water network vs. the cost of pumping additional water from the Shoalhaven River to the Wingecarribee Dam, a pumping lift of about 600 m.

It should be noted for residential reuse energy that this represents the extra energy to deliver recycled water into the consumers' taps. The values for the other systems represent the energy

Table 6
Comparative energy use

	Energy use, MWh/ML
Residential reuse	0.27
Agricultural reuse	0.38
Return flows	1.52
Recycled water network average	0.90
Shoalhaven–Wingecarribee transfer	2.40

cost to secure extra potable water deliveries to Prospect, to which must be added the energy costs for water treatment and delivery to consumers' taps. It can be concluded that freeing up additional Hawkesbury–Nepean water by constructing a recycled water network in western Sydney probably uses less than half of the energy needed to pump additional water from the Shoalhaven River.

6.4. Additional water recycling options

Coinciding with the release of the Metropolitan Water Plan, there has been some public debate about whether there should be additional water recycling supplied from new water reclamation plants in the coastal catchments. Certainly local opportunities in those catchments should be developed wherever economically and environmentally justified. But, until recycled water from the western Sydney treatment plants is fully utilised, and until there is a need for additional system yield over and above that provided for in the Metropolitan Water Plan, there appears to be little market justification to transfer large volumes of recycled water from Sydney's coastal catchments into the Hawkesbury–Nepean catchment.

There has also been some discussion about future options to return recycled water from the coastal catchments to the Sydney storages to supplement available freshwater resources. Such an option could have some cost, environmental or

energy advantages over pumping additional water from high flows in the Shoalhaven, but would require a significant shift in community and regulatory opinion. Certainly it is a matter worthy of public debate. Such a debate should be preceded by an open economic and environmental evaluation of the options.

7. Conclusions

An integrated water recycling system for western Sydney has a number of economic and environmental advantages. It can play a key role in providing a solution for the future water needs of Sydney, and in achieving the NSW government's objectives for restoration of the Hawkesbury–Nepean River system.

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