Water reuse and recycling in Australia: history, current situation and future perspectives

John C. Radcliffe*, Declan Page
CSIRO, Locked Bag 2, Glen Osmond, South Australia, 5064, Australia

ARTICLE INFO
Keywords:
Desalination
Drought
Managed aquifer recharge
Stormwater
Water recycling

ABSTRACT
Most of Australia has low rainfall. The population is small (25 M) but growing at 1.5%/yr. Water limitations are being exacerbated by climate change. By 1990, restraints placed on wastewater treatment plant (WWTP) discharges to receiving waters became an incentive for water recycling. The millennium drought (2000–2009) was a further driver for water recycling and desalination. Water reform policies, led to guidelines for recycled water, including stormwater and augmentation of drinking water. Advanced purified recycled water plants for indirect potable reuse were built in Brisbane. Dual pipes for drinking and recycled water were installed in new suburbs in Sydney, Melbourne and Adelaide. Agricultural, industrial and amenity recycled water use was expanded. Seawater desalination plants were installed in Gold Coast, Sydney, Melbourne, Adelaide and Perth. After the drought, economics further influenced the future use of recycled water. Since catchment water was cheaper than recycled or desalinated water, desalination plants were mothballed or maintained at low processing rates. Brisbane’s advanced water treatment plants were shut. Water policy complacency followed. However, Western Australia, which had declining rainfall, demonstrated to an accepting community that recycled water could be used for groundwater replenishment in Perth’s water supply. By 2019, drought conditions had returned to eastern Australia. Desalination plants were reactivated and Brisbane’s indirect potable recycling scheme prepared for reinstatement. Regional towns faced water shortages and were looking for diversity of water supply. Reviews have been undertaken of the future for direct potable recycling, a debate that needs to be initiated with the consuming public.

1. Introduction
Australia is a large country with a surface area of 7.7 M km². Much of the continent has very low rainfall (Fig. 1), is unsuitable for arable agriculture and falls within a generalised Köppen classification defined as desert (Fig. 2). There is also a high degree of variability in rainfall and temperature. Evidence is appearing of climate change and global warming. The annual national mean maximum temperature in 2019 was warmest on record (2.09 °C above average) [1]. The nationally-averaged rainfall for Australia (1961–1990) was 465.2 mm, but in 2019 was 40% below average for the year at 277.6 mm [1].

Australia’s present population of 25.4 M is less than 2% of that of China. Australia has an average population density of 3/m² with the densest settlements along the eastern and southern coastline and in the south west. It has become a highly urbanised country, with two-thirds of the population living in the five mainland states’ capital cities (Brisbane, Sydney, Melbourne, Adelaide and Perth) and the nation’s capital (Canberra), shown in Figs. 1 and 2. Ninety per cent of the population live within 100 km of the coast. In 2018–19, the population increase was 1.5%. Natural increase contributed 37% and net overseas migration contributed 63% of the population increase [2]. The rate of population growth is relatively high by comparison with other developed countries (e.g. Canada 1.4%, New Zealand 1.9%, United Kingdom 0.6%, USA 0.6%, China 0.5%, and Japan 0.2%) [3] and puts pressure on assurance of urban water supply.

European settlement began in Sydney in 1788, at which time the indigenous population has been estimated as upwards of 315 000 [4]. After their establishment, the Australian colonies were responsible for regulations. Having established colonial legislatures, their consequent policies developed independently of each other, though were generally based on English precedents.

The federation of the Australian colonies in 1901 through the Commonwealth of Australia Constitution Act resulted in the Commonwealth having powers for “Trade and commerce with other countries and...
among the States” [s. 51 (i)] and “external affairs” [s. 51 (xxix)]. Section 100 precluded the Commonwealth from “abridging the right of a State or its residents therein to the reasonable use of the waters of rivers for conservation or irrigation”. Water cycle management remained a states’ issue. Local government, established within the colonies prior to federation, became a third tier of government. However, the Commonwealth has influenced matters primarily of state responsibility, by providing finance to the states to bring in common policies, a mechanism that became increasingly important in the latter part of the 20th century through the evolution of environmental, natural resources and water management policies.

This paper describes the key elements of the history of how water recycled from wastewater, stormwater, roof catchments, and desalination of sea and brackish waters, has increasingly added supply diversity to Australia’s traditional catchment and groundwater water supplies.

2. Historical background – Urban water

2.1. Storage of catchment water

As the Australian colonies grew, each with a capital city, they accessed water courses and ground water, and in due course began to build catchment dams as a water supply. Capital city water supply authorities developed, owned since Federation by their state governments. The last major storage dam construction for urban water supplies occurred between 1950 and 1990 (Fig. 3). The largest included Warragamba (2000 × 10^6 m^3, supplying 80% of Sydney’s water, completed 1960), Thomson (1123 × 10^6 m^3, 60% of Melbourne’s water, completed 1986) and Wivenhoe (1165 × 10^6 m^3, 51% of Brisbane’s supply, completed 1986). Some minor capacity increases were completed after their initial construction. Tasmania (24 340 × 10^6 m^3, mainly for hydro-electricity generation) and New South Wales (24 814 × 10^6 m^3) have the largest storage capacity, while the Australian Capital Territory (124 × 10^6 m^3) and South Australia (261 × 10^6 m^3) have the least.

Considerable differences developed in the water storage provisions for the different cities. Brisbane could store six years’ water supply, principally in its Wivenhoe Dam which also served as a flood control dam. Sydney could store four years’ supply, Melbourne that for three years, while Adelaide could store only about ten months’ supply as it had since the 1940s been taking much of its urban water from Australia’s longest river system, the River Murray [6]. Perth became dependent for up to 60% of its water supply on groundwater from the Gnamgara Mound, part of the Yarragadee groundwater system.

2.2. Wastewater management

Wastewater was initially dealt with through use of open channels, cesspits and collection with night carts. Sydney discharged raw sewage into Sydney Harbour from the 1850s, but later built a sewage farm at Botany, operating from 1887 to 1916, by which time it was so overloaded that it was replaced by ocean discharge. About 90% Sydney sewage after only primary treatment, is still discharged to ocean by 4 km deep ocean outfall pipes at North Head, Malabar and Bondi [7–9]. Melbourne developed its 100 km² Werribee Sewage Farm in 1897 for beef production, and the Melbourne Water Corporation still operates the property, albeit having evolved it into a modern tertiary WWTP producing recycled water for industrial and agricultural use. The land area, now known as the Western Treatment Plant, has become one of the most popular sites for birdwatching in Victoria, with 284 species of birds recorded there from south-eastern Australia and east Asia.
Adelaide, settled in 1836, had 7000 cesspits under the city by 1877 and two years later built an underground water-borne sewerage system that discharged effluent to land at a 1.9 km² sewerage farm at Islington, north of the city. It continued in use until 1966 [10]. The scheme resulted in a 40% reduction in deaths in Adelaide from 23.5 per thousand population in 1880 to 14.3 per thousand in 1886 as a result of the almost complete elimination of typhoid in urban areas during that period [11].

Brisbane and Perth did not develop sewerage systems until 1911. In parts of Australian cities not provided with trunk sewerage systems, night carts were replaced by the septic tanks. These are not well understood or maintained by householders to this day [12]. In South Australia, schemes were established called Septic Tank Effluent Drainage Schemes (STEDS) bringing together the effluent from the tanks for further treatment, and in some cases, leading to the production of recycled water. All of these schemes could be considered early examples of water reuse.

It should be noted that unlike much of Europe and North America, no Australian cities except a small part of central Launceston, in Tasmania, adopted combined sewage-stormwater systems.

3. 1977: The first recycled water recommendations

An Australia-wide study commissioned in 1977 into strategies towards the use of reclaimed water [13] recommended:

- A national program of research, demonstration and education
- An integrated approach to water supply, sewerage and solid waste disposal as an integral part of one planning process
- Smaller, simpler sewer networks based on regional plants located near opportunities for reuse,
- A major thrust towards irrigation, both landscape and agricultural, with agricultural use reoriented to agricultural gain rather than disposal,
- Use for conserving water resources in rivers and streams and recharging aquifers providing nutrients were controlled
- The then current world potable water standards be extended, related to Australian conditions and applied to existing situations of inadvertent use
- Melbourne being seen as offering scope for a variety of reclaimed water uses
- Assessing the substitution of recycled water for freshwater in Adelaide and inadvertent groundwater recharge in Perth
- Assessing the elasticity of demand for various uses of water and the real cost of providing for variations in demand


![Water storage capacity of large dams, Australia-1857-2001](5) (1 GL = 1 x 10^9 m³).
Representative studies of the economics of reclaimed water projects where reclaimed water might be economic, encompassing issues of the definition of the reclaimed water ‘system’, to take into account savings in conventional water supply and waste disposal systems, use of marginal costs rather than average or historical costs and definitions of methods of financing reclaimed water schemes where comparisons over the total ‘system’ including social costs, show this to be economically preferable.

Development of conceptual models, pilot applications and some full scale projects, particularly for the ‘interception’ method (presumably ‘sewer mining’) and the ‘dual pipe’ supply concept.

In a follow-up report for Victoria it was concluded that water deficits would become a problem by 2000 [14]. There was little immediate response to these studies.

4. 1990–2000: Water recycling driven by the imposition of WWTP discharge standards

At about the time of the release of the Ecologically Sustainable Development Report in 1991, the Australia states began establishing environmental protection agencies and authorities. The potential environmental damage from inadequately treated sewage effluent being discharged to oceans, rivers and estuaries became recognised. Regulations were brought in setting standards for discharges. Sewage utilities sought to achieve regulatory standards by improving the composition of effluent discharges to water courses and water bodies, or alternatively, seeking uses for the discharges in the form of saleable recycled water.

In 1992, in recognition of the need to better manage water resources as a significant component of natural resource management, governments had created two Ministerial Councils comprising Commonwealth and States/Territories Ministers for agriculture, the environment and conservation. These were the Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) and Australian and New Zealand Environment and Conservation Council (ANZECC). These Ministerial Councils endorsed the development and implementation of a National Water Quality Management Strategy (NWQMS). The NWQMS involved governments jointly developing national water quality policies, processes, and guideline documents. The NWQMS initially comprised policy and principles (Guidelines 1–3); specific guidelines on water quality management and monitoring (4–10); and treatment and management of sewage systems (11–15 encompassing effluent management, trade wastes, sludge/biosolids management, reclaimed water use and sewage system overflows) [15]. Specific industry effluent guidelines (16–20, covering dairy sheds and processing plants, intensive piggeries, aqueous wool scouring and carbonising, tanneries and wineries and distilleries) were also developed [16]. The sewage system documents provided a basis for developments that included effluent and/or stormwater recycling. From the national guidelines, the states developed their own guidelines for the use of different qualities of recycled water for specific purposes, incorporated into regulations as necessary. Although the details differed between states, essentially there were four categories of recycled water. Those adopted by the Victorian EPA are given in Table 1. Comparable figures for Australian National Recycling Guidelines (which did not use categories), South Australia, Tasmania and California Title 22 are also available [17].

Two recycled water projects stand out as exemplars responding to the need to manage the environmental impacts of discharges from WWTPs. In 1993, New South Wales through its Recycled Water Coordination Committee, developed the NSW Guidelines for Urban and Residential use of Reclaimed Water (now superseded). This guidance placed a reliance on end point testing and monitoring. Using these guidelines to obviate damaging environmental discharges to Second Pond Creek, a residential “dual pipe” scheme with both drinking and recycled water supplies, was installed in the rapidly developing new Sydney suburb of Rouse Hill. Its WWTP could treat 4.4 × 10^6 m^3/day for reuse, with coagulation, flocculation, filtration and disinfection, initially including ozonation but subsequently with UV irradiation and super-chlorination. Care had to be taken to ensure there was no cross-contamination of the two water systems through incorrect pipe connections, especially through the house construction phase. Rouse Hill was a learning experience for the builders and plumbers. Over 50 cross-connections were found between the recycled and drinking water systems and had to be removed before the recycled water was brought on stream. Recycled water was conveyed in lilac (commonly called purple) 25 mm diameter pipes while drinking water was in conventional 20 mm pipes. Each line was managed through separate meters. The meter for recycled water was purple-coloured. Backflow devices were fitted to the drinking water lines but not to the recycled water [19]. The principal objective of the Rouse Hill Water Recycling Scheme was to reduce the nutrient loads on the Hawkesbury-Nepean River system caused by the discharge of treated wastewater, so environmental performance was assigned the highest weight. There were two license standards for Rouse Hill, one for discharge to the environment and the other for distribution to the recycled water system. Households used 40% less drinking water by having access to recycled water for toilet flushing, clothes washing, garden

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Water recycling Guidelines for the state of victoria, 2003 [18].</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class A</strong> (Highest Quality)</td>
<td><strong>QUALITY</strong></td>
</tr>
<tr>
<td>&lt;10 E. coli/100 ml; &lt;20 mg/L BOD; &lt;30 mg/L Suspended Solids pH 6–9 (90 percentile)</td>
<td><strong>PERMITTED USES</strong></td>
</tr>
<tr>
<td>Treatment includes Helminth reduction for cattle grazing use schemes</td>
<td><strong>Class B</strong> (or 2nd highest quality)</td>
</tr>
<tr>
<td>&lt;100 E. coli/100 ml; &lt;20 mg/L BOD; &lt;30 mg/L Suspended Solids; pH 6–9 (90 percentile)</td>
<td><strong>PERMITTED USES</strong></td>
</tr>
<tr>
<td>Agricultural e.g. Dairy Cattle grazing</td>
<td><strong>Class C</strong> (or 3rd highest quality)</td>
</tr>
<tr>
<td>Urban (non-potable): with controlled public access</td>
<td><strong>PERMITTED USES</strong></td>
</tr>
<tr>
<td>Industrial e.g. Washdown water</td>
<td><strong>Class D</strong> (or lowest quality)</td>
</tr>
<tr>
<td>Secondary treatment and pathogen reduction</td>
<td><strong>PERMITTED USES</strong></td>
</tr>
<tr>
<td>Agricultural: Non-food crops including instant turf, woodlots, flowers</td>
<td><strong>TYPICAL TREATMENT</strong></td>
</tr>
<tr>
<td>Secondary treatment and pathogen reduction</td>
<td>Secondary treatment</td>
</tr>
</tbody>
</table>


watering and car washing but used more water overall than the average Sydney household [20]. The Rouse Hill WWTP is now servicing 32 000 homes using purple pipes and fittings for supplying recycled water [21].

A second seminal demonstration of the use of recycled water as a response to environmental pollution risks occurred in Adelaide, where water from the Bolivar WWTP, Adelaide’s largest plant, was redirected to agricultural production. Adelaide’s treated effluent had previously been discharged to Gulf St Vincent. During the period 1949 to 1995, some 40 km² of seagrass was lost along the Adelaide coastline [22]. The Adelaide metropolitan WWTPs were required to develop Environmental Improvement Plans to upgrade the quality of the effluents they were discharging to ocean. There was concern that the marine ecosystem was being degraded by the 1300 t of nitrogen and 200 t of phosphorus in the 40 × 10⁶ m³ of outflow being discharged from the Bolivar WWTP annually, leading to loss of density in mangrove forests and the proliferation of large quantities of macroalgae as well as the loss of seagrass.

The initial response was to plan the building of a biological nutrient removal treatment plant. However, it was also recognised that Northern Adelaide Plains vegetable growers were withdrawing each year a total of 18 × 10⁶ m³ of groundwater from aquifers that could only sustainably support an annual abstraction of 6–10 × 10⁶ m³/yr. The groundwater cone of depression thus caused was resulting in saltwater being drawn into aquifers from the adjacent gulf, leading to deteriorating irrigation water quality. Bolivar WWTP effluent could be used as a resource to support horticultural irrigation on the Northern Adelaide Plains. The Bolivar plant was converted from trickling filters with secondary sedimentation and lagoon sedimentation to activated sludge. A Dissolved Air Floatation/Filtration (DAFF) plant was installed. The DAFF plant incorporated alum and polymer coagulation, flocculation, dissolved air floatation, granular multi-media filtration and chlorine disinfection. The stabilisation lagoons were retained for their natural biological and toxicological capacity, and as a buffer to minimise water quality deterioration from any abnormal industrial waste discharges. With a total volume of 4 × 10⁶ m³, they also provide 2 × 10⁶ m³ of additional storage to enable more water to be committed for sale in the summer. The outcome was the Virginia Pipeline Scheme, managed by a private company, Water Reticulation Systems Virginia Pty Ltd, which from 1999 provided access to 15 × 10⁶ m³/yr of tertiary treated Class A recycled water suitable for unrestricted horticultural use including spray irrigation of salad crops [17]. Produce from the scheme soon gained ready market acceptance. A similar project followed soon afterwards from the Christie’s Beach WWTP where the Willunga Basin Water Company, privately funded by growers, provided supplemental irrigation to the groundwater used for wine grape production [23].

4.1. Small urban recycling developments

Although it was realised that retrofitting large urban areas for use of recycled water could be difficult and uneconomic, innovative small developments were being introduced in housing subdivisions where former industrial sites were being repurposed for housing. At Fig Tree Place, Newcastle, New South Wales, a 27-unit subdivision on the site of a former tram depot in 1998 had incorporated water cycle management with Water Sensitive Urban Design (WSUD). Roof rainwater was collected in underground tanks. Surplus rainwater and stormwater from paving around the site was remediated in gravel-filled trenches, percolated to groundwater. The planning provided for the scheme to supply 50% of the in-house needs for hot water and toilet flushing, all domestic irrigation needs of the site, and supplement groundwater for all the bus-washing and irrigation needs of the adjacent Hamilton bus depot. Rainwater collection on the site reduced mains water consumption on the site by 54%, while stormwater run-off from the site was eliminated [24].

On the site of the former St Kilda Municipal Depot at Inkerman Street, St Kilda, Victoria, a site subject to 70% flooding, a 236-unit housing complex was developed. The initiative supported enhanced recycling of domestic greywater (bathroom basins, baths and showers), from about half the units in four buildings using an activated-sludge (aeration) tank, with secondary filtration in a 400 m² native wetland and sand filtration on the site. Recycling of the combined grey/stormwater for sub-surface garden irrigation and toilet flushing was provided across the entire development [25].

New Haven Village was developed as 65 medium density dwellings on 0.02 km² at Lefevre Peninsula, some 20 km northwest of central Adelaide, South Australia, being implemented with public and private participation in 1995. It operates an innovative water and wastewater management system including on-site treatment and re-use of household sewage (black and grey water) and a stormwater system which collects the first 50 m³ of a given rain event, the remainder being diverted to a sports field acting as a retention basin. This means that virtually no wastewater leaves the site. Recycled water for the New Haven Village is treated from wastewater, using primary sedimentation, aeration, and disinfection. It is used for house gardens, toilet flushing and an adjacent oval with irrigation systems that are not access sub-surface [26]. In a survey of residents, although 95% of respondents initially said they had no concerns, all described problems relating to water quality at some point in the interview. Every respondent reported occasional problems experienced with toilet flushing involving odour, a murky colour or sediment (or a combination of all of these). In all, 65% (13 respondents) described past, and less frequent, disruptions to the service that became evident through odour or the water being cut off. Although sub-surface irrigation was originally stipulated, except for the system installed on the adjacent oval, public open spaces have always been irrigated with sprays and the original display homes featured above ground microsprays as well as sub-surface drippers. Of the 20 respondents, 35% adapted their irrigation systems to suit their needs when problems were experienced with clogging of drippers and micro sprays [27]. The operation of the system is managed by a contractor under the aegis of the Port Adelaide – Enfield Council, a rate surcharge to the 62 properties being imposed to cover costs. The use of the recycled water is not metered.

These and many other recycling projects were described in a 2004 review of Australia’s water recycling [17]. It established that by 2001-2, over 500 WWTPs in Australia were recycling some or all of their treated wastewater. Treatment technologies underpinning the production of recycled water (however defined) included aerated lagoon; extended aeration; Pasveer channel; biological nutrient removal; activated sludge; oxidation and high rate oxidation lagoons; and trickling and high rate trickling filters. The first projects to harvest and treat stormwater had also been set in place.

Inland country towns were earlier adopters of water recycling than coastal and capital cities. This was well illustrated from figures from rural NSW where towns west of the Great Dividing Range recycled 50% of their wastewater, those east of the range recycled 20%, but coastal WWTPs were recycling only 2.5% of their wastewater. Whilst many of the WWTPs used their recycled water internally as process water, other uses were identified. These included amenity horticulture, beef pastures, bowling clubs, sugarcane fields, cattle feedlots, cemetery irrigation, cotton growing, dairy pastures, dune stabilisation, environmental water supplementation, forestry and woodlots, gold mines, golf courses, groundwater recharge, hydroponics; irrigated army firing range, lucerne growing, mineral processing water, native vegetation maintenance, nursing home gardens, parks, polo grounds, power generation/cooling, racecourses, showgrounds, sports fields, steel processing. Technical and further education college use, turf grass production, vegetables, and vineyards. The review [17] was cautious to suggest that widespread use of recycled water should be undertaken where water of drinking quality was not required. It was also suggested that there might be scope for use of indirect potable water recycling, but its introduction should only be progressed after community acceptance of its necessity.

A small number of examples was identified where recycling was undertaken within the confines of a single property. The most widely publicised was the house of lawyers Michael Mobbs and Heather Armstrong, who developed a pioneering example of onsite recycling on their
two-storey nineteenth century terrace house, on a block 35 m long and 5 m wide. It became one of the world’s first inner-city self-sufficient homes, located in the densely populated inner-west Sydney suburb of Chippendale. By developing a carefully protected roof catchment, they collected all rainfall, following an initial diversion, to a tank below the house-deck. All sewage from the house was collected in an underground concrete tank containing three filter beds and undergoing biological amelioration. The 100 m³/yr of effluent outflow, after UV disinfection, was used for toilet flushing, clothes washing and garden watering, with any excess going to a dry reedbed. Initially, there were occasional shortages of rainwater, and the sewage management scheme took about one year to function acceptably [28]. The house was totally disconnected from Sydney Water’s drinking water and wastewater systems as well as from the electricity system through use of solar panels. Putting his house on the market in 2019, Mobbs noted that his aerated wastewater treatment system recycling all grey and blackwater, had ensuring no raw sewage has left the premises in 23 years. But in recent years he had to increasingly rely on his neighbour’s garden hose to top up his storage tanks due to recent drought years with declining natural rainfall on his self-contained roof catchment [29].

New South Wales had adopted a strong planning framework through the Environmental Planning and Assessment Act 1979 (NSW) and the Local Government Act 1993 (NSW) setting objectives, policies and requirements for developments of defined state or regional significance. A further extension was the Building and Sustainability Index (BASEX) scheme, driven through the Environmental Planning and Assessment Regulation of 2000 and the 2004 State Environmental Planning Policy. Probably influenced by the public interest created by Mobbs’ house, BASEX, among other attributes, requires a 40% reduction in potable mains water use for all new residential developments and redevelopments compared with the average NSW annual potable water consumption from the residential sector of 90 m³ of water per person per year [30].

ACTEW, the then Australian Capital Territory (ACT) water utility, undertook trial installations of domestic-sized wastewater treatment plants in each of six houses in urban Canberra, commencing in 1994-5. The wastewater was either treated aerobically to a high standard and transferred to a holding tank on each block, or was managed with an intermittent activated sludge process, in which an air stream was used to keep organic material in suspension, but was periodically turned off, the suspended material then being allowed to settle and the clear effluent decanted from just below the surface. The treated and disinfected effluents from the systems were pumped for use within their respective property boundaries for toilet flushing and irrigation. A UV disinfection system was included at one site. The hydraulic loading of 100 m³ per person from three adult adults per household generated an irrigation loading of 600 mm/yr (The estimated average supplementary irrigation demand in Canberra is 643 mm/yr) Householders were encouraged to replace grass areas with deep-rooted trees, use low flush toilets, low flow shower roses, short showers to minimise water use in winter, and to use detergents sparingly to minimise salt loading in summer. The trial established from the user perspective that the approach was successful. The local standard that the effluent turbidity be < 2 NTU could not be met, but in practice would not have been required in the water, which was fit for the purpose it was being used. The total operating cost of $5000/yr to continue the trial over the 6 houses was considered acceptable. However, a health requirement that samples be collected and analysed fortnightly to meet biological monitoring standards at a cost of $5000/yr by the year 2000 for each dwelling was not acceptable at an individual household level [31].

5. 2000–2011: The millennial drought – security of supply as a driver for recycling

At the beginning of the twenty-first century, Australia entered a period of reduced rainfall, ultimately recognised as the “millennium drought”, extending for nearly ten years. A strategic framework for the reform of the Australian water industry has been agreed in 1994 at the Council of Australian Governments (COAG) comprising the Prime Minister, State Premiers and Territory Chief Ministers and a representative of the Australian Local Government Association. The Commonwealth encouraged the States/Territories to adopt the reforms by providing incentive payments when they had done so [32]. The reforms included separating the titles for land from rights to water, with both becoming separately tradable. Water resource management was separated from the water supply functions which were to be transferred to identify separate commercial corporatised entities, albeit mostly still government owned. Soon afterwards, those entities began imposing demand management policies and water restrictions on their customers in all the mainland capital cities. The Australian community became increasingly concerned that they would run out of water. Urban water issues were front and centre in the newspapers and discussed regularly on talk-back radio. Domestic users began to conserve their “grey water” (from baths, showers and washing machines), for use on their gardens, though for reasons of health and safety, they were discouraged from storing it longer than 24 h before use. Industries were required to introduce water efficiency measures. In some cases, they developed internal water recycling programs to maintain their commercial production systems.

The developing drought acted as an incentive to pursue further water reforms. During 2004–2006, the Commonwealth and the States and Territories progressively signed a 108 clause Intergovernmental Agreement on the National Water Initiative (NWI) [33]. The agreement encompassed clauses on water entitlements, water markets and trading, water pricing, management of environmental water, water accounting, urban water, community partnerships and adjustment, and knowledge and skills. It had objectives of ensuring healthy, safe and reliable water supplies; increased domestic and commercial water use efficiency; facilitating water trading between and within the urban and rural sectors; encouraging innovation in water supply sourcing, treatment, storage and discharge; and achieving improved pricing for metropolitan water. Specific references to water recycling included to:

- develop pricing policies for recycled water and stormwater congruent with pricing policies for potable water, and stimulate efficient water use no matter what the source, by 2006.
- develop national health and environmental guidelines for priority elements of water sensitive urban designs (initially recycled water and stormwater) by 2005.
- review institutional and regulatory models for integrated urban water cycle planning and management and develop best practice guidelines; - review incentives to stimulate innovation.

The National Water Commission (NWC) was established in March 2005, initially attached to the Office of the Prime Minister, though later transferred to the portfolio of the Minister responsible for water resources. The NWC was an independent statutory body created to drive the national reform agenda and assist with the effective implementation of the NWI. The NWC undertook two-yearly evaluations of progress by the states and territories in implementing the NWI.

The NWC became an unambiguous supporter of expanded use of recycled water, subject to four conditions, namely that cost/benefit and risk analyses were conducted - taking full account of social and environmental externalities and avoided costs; the best available science is utilised; the project is subject to best practice regulatory arrangements (based on the Australian Guidelines for Water Recycling); and the community participates in decisions to introduce recycling. Subsequent management arrangements were to be transparent and accountable.

The NWC was responsible for recommending to the Prime Minister, but later to the Minister for Environment and Water Resources, investments from the five-year $2B Australian Commonwealth Government Water Fund. This included two programs administered by the Commission. The first was the $1.6B Water Smart Australia program, targeted at large-scale projects to accelerate the development and uptake
of smart technologies and practices in water use across Australia. After 2008, this program was administered by the Department of Environment, Water, Heritage and the Arts. The Water Smart Australia program provided for investment in the conservation and more effective utilisation of water resources. “Diversity” through the provision of alternative water sources, became the new driver to ensure water security. This strengthened interest in water recycling as a component of ensuring reliability of supply. The Commonwealth government contributed financially to recycling and desalination initiatives across Australia. Within two years, 48% of the investment had been directed towards for water recycling projects. State governments also supplied complementary funds.

Projects were being developed as some cities faced “near emergency conditions”. For example, a statistically significant reduction in rainfall was recorded in Melbourne, the extended drought period being the worst on record with a probability of occurrence of cumulative inflow (1997–2006) being less than 0.002. It was concluded that the 39% reduction in long term average stream flows that had occurred since 1996 could represent a new planning base for Melbourne [34]. The City of Brisbane saw its water supply decline markedly, hitting a low point of <17% of storage capacity in August 2007. Under a long-term continuation of the 1997 to 2006 climate and then current water sharing arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35]. The mean annual run-off from Perth, from which Adelaide received much of its water, the surface catchment arrangements, average surface water availability for the Murray region from which Adelaide received much of its water, the surface catchment would decrease by 30% [35].

To aid public understanding of key water issues, the National Water Commission published 90 reports on key water issues including rainwater tanks, groundwater, desalination, recycled water for drinking and managed aquifer recharge in its “Waterlines” series [37].

5.1. Guidelines for recycled water, stormwater and managed aquifer recharge

A prerequisite for the greater use of recycled water was to develop a set of guidelines to cover the potential use of recycled water, storm water and Managed Aquifer Recharge (MAR) as components of an urban water system. This was achieved under the auspices of ARMCANZ, ANZECC and the National Medical Health and Research Council (NHMRC) through the development of a new set of National Water Quality Management Strategy Guidelines for water recycling. These were Phase 1 – Managing Health and Environmental Risks, and Phase 2 – Augmentation of Drinking Water Supplies; Stormwater Harvesting and Reuse; and Managed Aquifer Recharge. It has been observed that where these guidelines have been incorporated into state’s regulations, the use of MAR has been confidently facilitated, for example with recycled water [38] In 2011 the Australian Drinking Water Guidelines were redeveloped [15]. The Australian Guidelines for Water Recycling have defined safety using Disability Life Years (DALYs). Microbial safety is defined as <10⁻⁶ DALYs per person per year (identical to the WHO guidelines) which is equivalent to 1 day of diarrhoeal illness per 1000 people per year. DALYs measure impact in terms of severity and time. Specific log reductions to be achieved and potential treatment capabilities are set out in Table 2.

Cooking can achieve 5–6 log reductions. Using drip rather than spray irrigation may be worth 2 log reductions, while sub-surface irrigation may be worth 4 log reductions. By applying combinations of treatment and on-site control, potentially all sewage can be recycled. Minor revisions to the Phase 1 – Managing Health and Environmental Risks were circulated for comment in February 2020 by the Chair of the Environmental Health Committee (enHealth) Water Quality Expert Reference panel. The principles and the basic structure of the Guidelines were strongly supported and have not been changed. The draft update provides consistency with the more recently revised Australian Drinking Water Guidelines and WHO potable reuse guidelines.

5.2. Indirect potable water recycling and desalination

Examples of de facto indirect potable recycling (IPR) can be found in numerous places. An obvious example is treated effluent from Canberra’s Lower Molonglo WWTP ultimately flowing into the River Murray which can provide up to 80% of Adelaide’s drinking water in dry seasons [39]. These processes are little recognised by the consuming public. Although some states had previously announced policy bans on IPR, the first test of the introduction of IPR water into a drinking water system occurred in 2007 in Toowoomba, Queensland, located on the crest of the Great Dividing Range 130 km inland from Brisbane. A proposal was developed for the recycling of wastewater from the upgrading of the Wetalla WWTP for agricultural irrigation and for IPR via the Cooby dam. The Australian Government agreed to contribute $22.9 M to the then $67.8 M cost from the Water Smart Australia programme subject to community support in a referendum. In the event, the debate became very polarised around various personalities and the underlying principles were not well appreciated by the community. A review identified biases in information processing, with supporters and opponents selectively attending to information aligned with their own values [40]. The referendum to adopt the use of purified recycled water was lost 32 220 (61.6%) to 19 983 (38.2%) of the votes cast [41]. Ultimately, in early 2010, Toowoomba was connected to the South East Queensland Water Grid at a cost of $187 M, with the Toowoomba Council required to pay more than half the costs of this much more expensive option. The chosen solution had an operational energy cost of 3.11 kWh/m³ compared to 2.22 kWh/m³ for the original Wetalla Advanced Wastewater Treatment Plant (AWTP) supply to the domestic tap [42].

Despite the result of the Toowoomba referendum, the position in Brisbane was becoming dire. Brisbane’s daily consumption was reduced from 300 L to 139 L per person. The Queensland government proceeded to develop AWTPs adjacent to three WWTPs at Bundamba, Luggage Point and Gibson Island. The scheme, known as the Western Corridor Scheme, was based on the manufacture of 84 × 10⁶ m³/yr of what was described as purified recycled water by microfiltration, reverse osmosis and advanced oxidation [43]. The recycled water was to be pumped to the Wivenhoe Dam as a form of indirect potable use. The Queensland Premier advised that government research showed that 78% of people supported the scheme. The project was directed to two power stations which were then using 10% of Brisbane’s daily drinking water consumption. From August 2007 to September 2008, the power stations were provided with 25 × 10⁶ m³ of water for cooling from the Advanced Water Recycling Plants. Brisbane’s water resources were linked together to form a newly constructed water grid. The project components were

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Required log reductions for recycled water, calculated from exposures associated with specific uses and treatment capability [38].</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity</td>
<td>Exposure Litres per year</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Residential use – toilet flushing, gardens</td>
<td>0.67</td>
</tr>
<tr>
<td>Commercial crops – salad vegetables</td>
<td>0.49</td>
</tr>
<tr>
<td>Irrigation of parks – public access</td>
<td>0.05</td>
</tr>
<tr>
<td>Drinking water</td>
<td>300-750</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total log reduction required</th>
<th>Bacterial</th>
<th>Viruses</th>
<th>Protozoa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorination</td>
<td>2.0-6.0</td>
<td>1.0-3.0</td>
<td>0-1.5</td>
<td></td>
</tr>
<tr>
<td>UV light</td>
<td>2.0 - &gt; 4.0</td>
<td>1.0 - &gt; 3.0</td>
<td>&gt;3.0</td>
<td></td>
</tr>
<tr>
<td>Filtration and disinfection</td>
<td>&gt;5</td>
<td>5-6</td>
<td>3-4</td>
<td></td>
</tr>
</tbody>
</table>
completed urgently within 2 years [44]. The total infrastructure cost of the South East Queensland developments was $2.5B. The scheme through its connection via the Wivenhoe Dam to the Queensland water grid has the potential to supply IPR water to Toowoomba as well as Brisbane.

Other direct and IPR proposals were discussed in Queensland, including for Noosa, Caloundra and Maroochy and Caboolture. In each of these cases as well as in Toowoomba, vocal community groups had arisen under the title of CADS ("Citizens Against Drinking Sewage") and none of these proposals were implemented [45].

Proposals were also explored in New South Wales and the Australian Capital Territory. Community consultations for IPR water recycling to be adopted in Goulburn NSW were held in 2006 [46], but the alternative of a pipeline from the Wingecarribee Reservoir was ultimately adopted. Canberra ACT conducted community consultations in April–June 2007 for adding recycled water to its Cotter dam, but the scheme was finally deferred [47].

Despite some community concerns regarding their high energy consumption, seawater desalination plants were urgently developed for Sydney (90 × 10^6 m³/yr), Melbourne (150 × 10^6 m³/yr), Queensland’s Gold Coast (Tugun, 45 × 10^6 m³/yr), Adelaide (100 × 10^6 m³/yr), and Perth (45 × 10^6 m³/yr). These plants involved a variety of design, funding, and technical development methods, but all were fundamentally dependent on energy intensive reverse osmosis. Perth completed its desalination plant at Kwinana first, and then built a second plant (100 × 10^6 m³/yr) at Binningup, 150 km south of the city, its electricity needs funding, and technical development methods, but all were fundamentally dependent on energy intensive reverse osmosis. Perth completed its desalination plant at Kwinana first, and then built a second plant (100 × 10^6 m³/yr) at Binningup, 150 km south of the city, its electricity needs secured by purchasing all outputs from two renewable resources. The power requirements for the desalination plants varied from 3.6 to 5.0 kWh/m³ of water produced, compared to 1.0 kWh/m³ for the Western Corridor Advanced Water Recycling Plants in Brisbane, pumped transport to the Wivenhoe Dam representing another 1.0 to 1.5 kWh/m³ [48].

Western Australia began exploring a major approach to recycling through groundwater replenishment. At the Western Australian Water Corporation’s Beenyup WWTP, MF/RO and advanced oxidation were introduced in a pilot plant to produce recycled water for injection into the Leederville aquifer where it was being further remediated by natural groundwater processes, injection being at a location remote from existing drinking water bores. The plant potentially provided 1.5 × 10^6 m³/yr of additional drinking water for Perth. The three-year research project completed in December 2012, was evaluated by regulators from the Department of Environment and Conservation, Department of Health and Department of Water. They indicated that the trial had met all the project objectives and that groundwater replenishment was feasible. An associated communications approach with tours and an interpretive centre, proved successful with the 2012 Annual Community Survey indicating that community support for a full-scale groundwater replenishment scheme remained steady at around 76% [49]. In consequence, an advanced water recycling plant of capacity 14 × 10^6 m³/yr was built by 2016 for managed aquifer recharge. This was followed by a stage 2 expansion in 2019 involving an adjacent advanced water recycling plant, drilling four new recharge bores and four new monitoring bores in Wanneroo and Neerabup and building a 13 km recharge pipeline connecting the advanced water recycling plant with the new bores [50], for a total replenishment capacity of 28 × 10^6 m³/yr.

The millennium drought resulted in the construction in a very short space of time of eleven major plants for the production of recycled water suitable for contributing to drinking water systems. These major urban water recycling and desalination plants are summarised in Table 3.

### Table 3

<table>
<thead>
<tr>
<th>City/Location (State)</th>
<th>Capacity (10^6 m³/yr)</th>
<th>% annual demand</th>
<th>Delivery method</th>
<th>Owner</th>
<th>Contract</th>
<th>Status (2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advanced Water Treatment Plants – Immediate Potable Recycling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brisbane – Bundamba (Q)</td>
<td>24</td>
<td>30</td>
<td>Alliances - three treatment plant alliances, plus two other transfer system (pipelines) alliances</td>
<td>Queensland Manufactured Water Authority (WaterSecure)</td>
<td>10</td>
<td>Decommissioned 2012</td>
</tr>
<tr>
<td>Brisbane – Gibson Island (Q)</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brisbane – Luggage Point (Q)</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perth – Beenyup-I (WA)</td>
<td>14</td>
<td>10</td>
<td>Competitive Alliance</td>
<td>Water Corporation (Operator - Aroona PPP)</td>
<td>n.a.</td>
<td>Decommissioned except two trains 2012</td>
</tr>
<tr>
<td>Perth – Beenyup-II (WA)</td>
<td>14</td>
<td></td>
<td>Competitive Alliance</td>
<td>Water Corporation (Operator 2016)</td>
<td></td>
<td>Refitting commenced 2019</td>
</tr>
<tr>
<td><strong>Seawater Desalination Plants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sydney – Kurnell (NSW)</td>
<td>90</td>
<td>15</td>
<td>Design, Build, Operate for Sydney Water, then lease</td>
<td>50 year lease to Sydney Desalination Plant Pty Ltd</td>
<td>50</td>
<td>Full capacity 2019–20</td>
</tr>
<tr>
<td>Melbourne – Wonthaggi (Vic)</td>
<td>150</td>
<td>33</td>
<td>Build, own, operate – public private partnership (PPP)</td>
<td>Private owner - Aquasure</td>
<td>30</td>
<td>Full capacity 2019</td>
</tr>
<tr>
<td>Gold Coast/Brisbane – Tugun (Q)</td>
<td>45</td>
<td>18</td>
<td>Alliance – Design, build, operate</td>
<td>Seawater</td>
<td>10</td>
<td>First water contract 2017</td>
</tr>
<tr>
<td>Adelaide – Lonsdale (Port Stanvac) (SA)</td>
<td>100</td>
<td>Up to 50</td>
<td>Alliance – Design, build, operate, maintain</td>
<td>SA Government</td>
<td>20</td>
<td>Full capacity from 2019</td>
</tr>
<tr>
<td>Perth – Kwinana (WA)</td>
<td>45</td>
<td>16</td>
<td>Competitive Alliances</td>
<td>Water Corporation</td>
<td>25</td>
<td>Full capacity 2019</td>
</tr>
<tr>
<td>Perth – Southern Binningup (WA)</td>
<td>100</td>
<td>35</td>
<td>Design, construction and operation</td>
<td>Water Corporation</td>
<td>25</td>
<td>Full capacity 50–80 × 10^6 m³/yr.</td>
</tr>
</tbody>
</table>

5.3. Recycling within industry

Meanwhile, water restrictions and water efficiency audits were leading to an increased demand for recycled water by industry. Oil refineries in Geelong (Victoria) and Brisbane adopted the use of recycled water within their production systems. Foster’s Brewery at Yatala, Brisbane, after a one-twentieth scale pilot trial, established its own internal plant for recycling washwater used in the brewery. From 2005, the plant averaged 1.5 × 10^3 m³/d water recovered, equivalent to 65% of its effluent stream. The final recycled product is considerably purer than Brisbane water supply, typically 80 mg/L TDS. (The water is not used in the final production of the beer.) The amount of water used to produce 1 m³ of beer was reduced from 6.0 to 2.2 m³ and the resultant effluent, mainly washwater, was reduced from 4.5 to 0.9 m³/m³ beer with major savings in water and discharge costs [51]. In Western Australia, by 2004, the Kwinana Water Reclamation Plant was taking 24 × 10^3 m³/d of secondary treated wastewater from the Woodman Point WWTP to...
provide $17 \times 10^3 \text{ m}^3/\text{d}$ of high-quality industrial grade water (40–50 mg/L TDS) for five large Kwinana heavy industries.

5.4. Localised urban WWTP recycling schemes

By 2008, there were 14 recycling schemes in place in and near Sydney, the majority for irrigation, each usually having only one customer (Table 4) [52].

One of the largest NSW schemes was south of Sydney, the Northern Shoalhaven Reclaimed Water Management Scheme undertaken by the Shoalhaven City Council in 2002 to beneficially re-use 80% of the reclaimed water produced by six WWTPs in the Shoalhaven region. After a successful process of community, stakeholder and end-user consultation occurring over a 12-year period, the scheme supported 5 km² of irrigation on 20 dairying properties [53]. It was being further extended in 2019 with WWTP upgrades at Bombaderry and Nowra brought on-line.

A significant example of Industrial use developed from the 50 $\times 10^3 \text{ m}^3$/day of recycled water from the Wollongong WWTP activated sludge plant. Tertiary treated UV and chlorinated recycled water was introduced for coal washing at Port Kembla Coal and irrigation of local parks and the Wollongong Golf Club. From this was also generated 20 $\times 10^3 \text{ m}^3$/d of very high-quality recycled water by microfiltration/reverse osmosis for use in manufacturing at BlueScope Steel. Any not required is discharged to ocean [54]. Effluents from the St Mary’s, Quakers Hill and Penrith WWTPs were brought together at St Marys WWTP to generate 8 $\times 10^6 \text{ m}^3$/day of environmental flows into the Hawkesbury-Nepean River to replace upstream abstractions for economic use. Hunter Water creatively developed recycling at Newcastle, NSW for use in cooling in the Eraring Power Station, but unexpectedly lost some of its potential industrial market when the city’s steelworks closed, highlighting the importance of ensuring continuity of demand when developing recycling projects.

Sydney continued to develop plans for many more urban dual piping systems in new “greenfield” suburbs. Two thousand apartments at Newington were provided by the Sydney Olympic Park Authority with recycled water from microfiltration/reverse osmosis by combining effluent sources from the Olympic Park WWTP, sewer mining from Sydney Water and wetland-remediated stormwater collected from old brick pits [55]. Sydney Water developed a long-term view of the potential for wider use of recycled water in dual pipe domestic systems. Ten- ders were called for provision of infrastructure to ultimately service 14 000 homes and industrial demand in the south-west growth area based on Hoxton Park [56,57]. Sydney Water was aiming to have 25 more water recycling schemes in place by 2015, supplying 12% of Sydney’s water needs [52]. Planning ultimately provided that the Western Sydney Recycled Water Initiative (WSRWI) would provide recycled water via dual reticulation to 160 000 new homes to be built in suburbs in Sydney’s North-West and South-West (Fig. 4).

The Declaration of Sewage Services by the National Competition Council followed the Tribunal recommendation in favour of an application by the company Services Sydney to have the Sydney sewerage services market opened to private competition [59]. This resulted in the New South Wales parliament passed the Water Competition Act (2006) which allowed private sector companies to develop and sell water products in competition with the previous monopoly supplier, the state government-owned Sydney Water Corporation. The first to do so was AquaNet Sydney Pty Ltd, a joint venture created in 2008 between the Jemena Corporation (owned by State Grid Corporation of China and Singapore Power) and Veolia. Using ultra filtration, reverse osmosis and cation exchange, the Jemena Rosehill Recycled Water scheme includes the Fairfield Recycled Water Plant with a capacity of 20 $\times 10^3 \text{ m}^3$/d, two pump stations and three reservoirs connected by 20 km of pipeline. Some of the pipelines were repurposed redundant gas pipelines. The plant produces $4.3 \times 10^6 \text{ m}^3$/yr recycled water for major industrial and commercial customers in Rosehill and Smithfield, thereby reducing demands on drinking water supplies. Approved uses are water for cooking tower make-up, industrial process, wash-down, fire fighting, irrigation, washing machine (cold water tap only) and toilet flushing [60]. The scheme is now owned by Water Utilities Australia.

During the Millennium drought, the regional NSW city of Orange incorporated stormwater from its 34 km² Blackmans Swamp and Ploughman’s Creeks catchments, 67% of which were urban streetscapes, into its drinking water supply. The scheme used wetland remediation with a $200 \times 10^3 \text{ m}^3$ settling pond, followed by coagulating batch ponds leading to the existing Suma Park Dam. Subsequent water treatment was by coagulation, sedimentation, filtration, ozonation, biological activated carbon (BAC) and chlorination. The annual yield from the stormwater system is $1.3 \times 10^6 \text{ m}^3$ [61]. The scheme has been reviewed as a case study [62].

By 2008, “fit-for-purpose” recycled water in various forms had also progressively evolved for use in third pipe reticulation systems to new housing developments in other Australian cities. Recycled water was being supplied through dual reticulation in the Melbourne (Victoria) suburb of Aurora by 2009. A population of 25 000 residents was anticipated. In the next 25 years, 50 000 Melbourne homes were expected to have dual reticulation. Other areas developed include Cranbourne (encompassing Sandhurst Park and Hunt Club Estate) based on the Eastern Irrigation Scheme’s original ultrafiltration/chloramination plant located near to Melbourne Water’s Eastern Treatment Plant. After considering the results from an experimental comparison of four reverse-osmosis based membrane treatment trains, Melbourne Water’s Eastern Treatment plant was redeveloped using ozonation and biological activated carbon media filtration for its Advanced Tertiary Treatment Plant which now supplies the Eastern Irrigation scheme directly [63], the original plant being bypassed. Class A recycled water ($5 \times 10^3 \text{ m}^3$/d capacity) was being supplied from the Western Water Corporation Melton WWTP based on a MF/UV/chloramination treatment train for availability in subdivisions at Eynesbury and Melton South [64]. Melbourne retailer City West Water operated from mid-2007, a scheme in the

---

Table 4

Water recycling schemes in and near Sydney, New South Wales 2009 [52].

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Type</th>
<th>Year Started</th>
<th>End uses</th>
<th>Number of customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rouse Hill</td>
<td>Residential</td>
<td>2001</td>
<td>Toilet flushing</td>
<td>18 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Outdoor use</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fire Fighting</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Washing machines</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ornamental Ponds</td>
<td></td>
</tr>
<tr>
<td>Wollongong Stage 1</td>
<td>Industrial</td>
<td>2006</td>
<td>Industrial open system</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fire fighting</td>
<td></td>
</tr>
<tr>
<td>Wollongong Stage 2</td>
<td>Industrial &amp;</td>
<td>2009</td>
<td>Industrial open system</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>irrigation</td>
<td></td>
<td>Fire fighting, irrigation</td>
<td></td>
</tr>
<tr>
<td>Bombo</td>
<td>Irrigation</td>
<td>1995</td>
<td>Controlled access irrigation</td>
<td>1</td>
</tr>
<tr>
<td>Castle Hill</td>
<td>Irrigation</td>
<td>1983</td>
<td>Uncontrolled access irrigation</td>
<td></td>
</tr>
<tr>
<td>Liverpool</td>
<td>Irrigation</td>
<td>1980</td>
<td>Controlled access irrigation</td>
<td>2</td>
</tr>
<tr>
<td>Gerroa</td>
<td>Irrigation</td>
<td>2001</td>
<td>Uncontrolled access irrigation</td>
<td>1</td>
</tr>
<tr>
<td>Penrith Scheme</td>
<td>Irrigation</td>
<td>1994</td>
<td>Controlled access irrigation</td>
<td>1</td>
</tr>
<tr>
<td>Penrith Scheme</td>
<td>Irrigation</td>
<td>2007</td>
<td>Uncontrolled access irrigation</td>
<td>1</td>
</tr>
<tr>
<td>Picton</td>
<td>Irrigation</td>
<td>1974</td>
<td>Uncontrolled access irrigation</td>
<td>1</td>
</tr>
<tr>
<td>Quakers Hill</td>
<td>Irrigation</td>
<td>1967</td>
<td>Uncontrolled access irrigation</td>
<td>2</td>
</tr>
<tr>
<td>Richmond</td>
<td>Irrigation</td>
<td>1999</td>
<td>Uncontrolled access irrigation</td>
<td>1</td>
</tr>
<tr>
<td>St Mary’s</td>
<td>Irrigation</td>
<td>2007</td>
<td>Agriculture</td>
<td>1</td>
</tr>
<tr>
<td>West Camden</td>
<td>Irrigation</td>
<td>2007</td>
<td>Agriculture</td>
<td>1</td>
</tr>
</tbody>
</table>
Werribee Technology Precinct drawing Class A recycled water (Table 1), which had UV and chlorine disinfection, from Melbourne Water’s Western Treatment Plant via a 6 km pipe which was supplying $315 \times 10^3$ m$^3$/yr for non-residential use. The Werribee recycled water was available to vegetable growers through Southern Rural Water from mid-2006, with capacity to supply $8.5 \times 10^5$ m$^3$/yr to 100 growers. Increasing recycled water salinity and consequent soil impacts became a problem. From time to time, the recycled water has been diluted with river water. However, salinity increased as a result of continued salt intrusions and reduced influent volume to the Western Treatment Plant as Melbourne’s millennium drought water restrictions increased [65].

Recycled water was also being adopted more widely throughout Victoria for parks and sporting amenities, industries, environmental flow substitution, and to achieve discharge standards to receiving waters now required of wastewater treatment plants. Urban examples included City West Water, which upgraded its WWTP in industrial Altona using Intermittently Decanted Extended Aeration (IDEA) to supply $1.5 \times 10^6$ m$^3$/yr recycled water to plastics manufacturer Qenos, Kooringal and Sanctuary Lakes Golf Course and the Altona Green reserve. An innovative approach was taken at Sunshine, where a developer was establishing a new golf course with a small recycling plant for the Sunshine Golf Club in exchange for the old golf course which was developed into Callaway Park, a 640 lot subdivision. The recycling plant takes influent by mining an adjacent sewer, then uses two identical Extended Aeration activated sludge packaged treatment plants, each capable of operating independently with common tertiary filtration and UV disinfection. After completion, the recycling plant passed from the developer to City West Water for operation. It generates $90 \times 10^3$ m$^3$/yr. To provide for heavy summer golf course irrigation demand, a $30 \times 10^3$ m$^3$ winter storage has been built on the golf course. A total of about $10 \times 10^5$ m$^3$ of stormwater per year is also available for greens irrigation.

In northern Victoria, the Bendigo Epsom WWTP, operated by Coliban Water, was upgraded to tertiary status to produce Class A recycled water (Table 1) using a treatment train of biological nutrient removal, UV radiation, chlorination, dechlorination, with a side-stream UF/RO plant for salinity reduction for amenity and domestic non-potable use [66]. During the drought, water was supplied to droughted $60 \times 10^3$ m$^3$ Lake Weeronga for water sports, it having been estimated that with the potential ingestion of recycled water by rowers of 0.3 L/person/yr, the water quality risks assessment were considered acceptable [67].

In eastern Victoria, the Gippsland Water Factory was brought on-line in 2011 to treat $35 \times 10^3$ m$^3$/d of wastewater from nine Gippsland towns, and Australian Paper’s Maryvale mill using anaerobic pre-treatment and a membrane bioreactor to generate $8 \times 10^3$ m$^3$/d Class A recycled water (Table 1) for industry. The factory’s Vortex Centre, which was built over a constructed, 3.5 m deep lake, includes a public education facility where people, including children, can learn more about the water cycle, water conservation and sustainable water management.

The Queensland government established the Queensland Water Recycling Strategy [68] with implementation by the Queensland Environmental Protection Agency, to enable Queensland to use recycled water more effectively and efficiently, to accommodate increases by 40% in population over the following 21 years and to support economic growth while helping to protect the environment and safeguarding public health.

Gold Coast Water, a business unit of Gold Coast City Council in southeast Queensland, established the Pimpama-Coomera Waterfuture project to investigate the sustainable provision of urban water services. The project area is located south of Brisbane in an area whose population was growing fast with an additional 150 000 residents anticipated by 2050.
The then current housing stock of 2500 was predicted to reach 26 756 by 2021. The region is water resource constrained and treated water release sites are adjacent to environmentally sensitive areas. The Gold Coast City Council embarked on a new integrated urban water management planning approach. In 2002, it initiated an Advisory Committee involving a broad range of stakeholders, including community members, to develop the Master Plan from its earliest stage. Targets were set in comparison to a business-as-usual model, including:

- replacing 25% of drinking water with other sources for non-drinking uses;
- setting a maximum of 40 kg nitrogen release per day from the regional WWTP,
- releasing $12.5 \times 10^3$ m$^3$/d treated water with 5% less stormwater flow, and a 15% reduction in peak instantaneous water demand rates,
- 30% reduction in potable water system retention,
- 20% net reduction in greenhouse gas emissions,
- defer or eliminate the need for new surface water storages,
- improved consumer acceptance response to the service provided and improved local amenity,
- no increase in the whole-of-life cost to the community for all services.

It was determined following consideration of the report [69] that all houses built in Pimpama-Coomera after August 2005 were to have Class A+ recycled water (Table 1) in third pipe systems.

In South Australia, the dual reticulation Adelaide suburb of Mawson Lakes, developed between 2005 and 2010, uses a mixture of recycled wastewater from the dissolved air flotation filtration (DAFF) plant at the Bolivar WWTP and wetland-recycled stormwater stored by MAR from the City of Salisbury’s Salisbury Water Company. The scheme serves 10 000 residents in 4000 homes together with 6000 workers and 7500 students in educational institutions [70]. To the south of Adelaide, Water Smart Australia funding contributed to the initiation of dual reticulation for 8000 homes at Seaford Meadows, based on an upgrade of the Christies Beach WWTP using Integrated Fixed-Film Activated Sludge technology. Recycled water, produced by ultrafiltration and chlorination/UV sterilisation from the Glenelg WWTP, is used to service Adelaide airport toilets and gardens and keep the Adelaide Parklands green throughout the year. A minimum of $1.3 \times 10^3$ m$^3$ is supplied annually through purple pipes to enable the parklands irrigation which also serves to offset the “heat island” effect of the city. Irrigation of the surrounds of Adelaide airport runways to reduce heat effects has also been shown to reduce fuel consumption and increase take-off maximum loads on hot mid-summer days [71]. Glenelg recycled water is also provided for toilet flushing to residents in the inner Adelaide suburb of Bowden [72].

At the Perth coastal suburb of Cottesloe, stormwater previously discharged through ten ocean outfalls, is now being injected into the underlying aquifer after underground stormwater treatment using storage and recharge tanks with the addition of 280 roadside soak pits. The recharge offsets use from numerous domestic bores and reduces the risk of potential saline intrusion. Both projects were supported by Smart Water Australia [73].

5.5. Internal recycling in high-rise buildings

The process of demonstrating the potential to recycle water within the designs of new buildings was led by several of the water corporations themselves. Sydney Water occupied a new head office at Parramatta from 2009 incorporating using 75% less drinking water with wastewater discarded to the sewerage system being reduced by 90%. On-site recycled wastewater was used for toilet flushing, cooling towers, fire testing and irrigation supplemented by a 100 m$^3$ rainwater tank. Melbourne Water Corporation moved to a new building in La Trobe Street in 2012, featuring 50 m$^3$ of rainwater storage, which is filtered for use in hand basins and showers. Vacuum-flush toilets (like those used on aircraft) have been utilised to significantly reduce water consumption, with each toilet using just 1.0 L of water per flush. Meanwhile, the Melbourne City Council had built “Council House 2” which encompasses the daily extraction of 100 m$^3$ of raw sewage by sewer mining from Little Collins Street adjacent to the building, adding it to wastewater from the building itself. After treatment, the recycled water is added to harvested rainwater and supplies 100% of the building’s needs for cooling water, toilet flushing and amenity plants watering [74]. A nineteenth century Melbourne office building at 60 Leicester Street Carlton occupied by the Australian Conservation Foundation was retrofitted for full water recycling incorporating rainwater harvesting, waterless urinals and an in-house biological WWTP, with water from it being used to flush toilets and irrigate the internal and rooftop gardens [75]. The South Australian Water Corporation moved to a new building in Victoria Square which had water efficient taps, toilets and waterless urinals with AAAA rating. The building used 70% less mains water than a conventional office building – saving $1 \times 10^3$ m$^3$/yr water by using recycled water and rainwater for toilets. Self-contained treatment systems may also have advantages where additional available sewerage capacity is limited.

5.6. Rainwater

Rainwater, (sometimes called tankwater), is the traditional form of conservation for reuse in areas without reticulated water supply. A 1994 survey by the Australian Bureau of Statistics showed that 13% of all Australian households used a tank as a source of drinking water, the mean across all capitals being only 6.5%, while 30.5% of rural households had one [76]. The highest use was in South Australia with 37% of households having tanks, with 82% of the South Australian rural population having rainwater as their primary source of drinking water compared to 28% in metropolitan Adelaide [77]. Even with the provision of first flush diversion devices, it can be difficult to achieve drinking water biological standards in urban rainwater tanks. Urban areas, as well having a native bird and mammal population, also have a considerable population of feral animals and domestic pets, primarily cats and dogs. Rainwater tanks can be contaminated by faecal droppings and various species that can enter the tank, apart from the risk of mosquito breeding and the potential increased risk of mosquito-borne diseases such as Murray Valley Encephalitis and Ross River Fever virus diseases. Natural attenuation of potentially pathogenic organisms can occur in rainwater tanks as well as in stormwater ponds, sewage lagoons and groundwater basins provided there is an adequate dwell time [78]. However, tanks are frequently poorly maintained by owners. Some local governments prohibited the collection of rainwater [79]. A revised edition of Guidelines for the Use of Rainwater Tanks was released in 2011 by the Environmental Health Committee (enHealth) of the Australian Health Protection Committee, which brings together top Environmental Health officials at the Federal and State/Territory level [80]. Rainwater is also covered in the NWQMS stormwater recycling guidelines.

The millennium drought changed attitudes to rainwater collection at the domestic scale from home roofs. The drought that began affecting much of Australia from 2001 to 2003 resulted in water restrictions being imposed in Sydney, Melbourne, Canberra, Perth and South-East Queensland. A re-evaluation of the use of rainwater tanks in urban areas occurred. Incentives were introduced to encourage their installation. The New South Wales government had a subsidy scheme until 30 June 2005 to encourage tank purchases and installation. The scheme provided subsidies ranging from $150 for tanks of 2000–2999 L capacity to $500 for tanks >7000 L. An additional $150 was offered if a toilet and/or washing machine were connected to the rainwater tank. The Victorian government introduced a subsidy of $20 on $100 worth of water saving equipment. Buyers of a 600 L rainwater tank could get a rebate of $150. Installing a greywater recycling system, which previously attracted $150, from 1 January 2004 became eligible for a $500 grant where the installation had cost >$1500 [17]. However, a major increase in energy requirement occurs if pressurised rainwater tanks with domestic pumps are introduced as can arise, for example, in using rainwater and...
pasteurisation for the hot water system. Properties with self-contained rainwater and greywater domestic systems, which depended on small electric pumps and UV disinfection units for their successful functioning, had an average energy use of 4.3 kWh/d, compared with a water and sewage grid supply equivalent value of about 0.6 kWh/d [81].

Ultimately, the Water Smart Australia program ran until June 2012 and contributed funding of $1.48B towards 78 projects with total costs of $4.96B [82].

5.7. Recycling and desalination research resources

The millennium drought also served to strengthen research initiatives into water cycle management and pursuit of diversity of supply. A comprehensive set of 77 papers was presented at the International Conference in Water Recycling held in Wollongong in February 2005 [83]. To continue the development of new technologies to underpin the adoption of alternative water resources, the Australian government agreed in 2009 to support five years’ funding totalling $20 M each for the creation of Centres of Excellence in water recycling and desalination. The Australian Water Recycling Centre of Excellence (AWRCoE), established in March 2010, was hosted in Brisbane by Western Corridor Recycled Water Pty. Ltd. (“WaterSecure”), followed by the Queensland Bulk Water Supply Authority (Seqwater). Founding partners were University of Queensland, Griffith University, University of New South Wales and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), along with industry partners including Veolia Water Australia Pty. Ltd. and GHD Pty. Ltd. A Strategic Research Plan identified 44 Priority Research topics that were allocated across the four goals, viz Goal 1 - The social/economic/environmental value of Water Recycling; Goal 2 - A national validation framework for Water Recycling that would underpin future recycling technologies and installations; Goal 3 - Reclaimed water for augmenting drinking water supplies; and Goal 4 - A national knowledge, training and education program for Water Recycling. With co-investment in its projects, the Centre operated for seven years and undertook thirty projects with a total investment of over $50 M. Projects included the evaluation of various recycling projects and lessons learned [23], the development of a small potable recycling plant suitable for use at an Antarctic base [84] and validation processes as components of accrediting water recycling, marketed as “Waterval” [85]. Excellent collaboration developed with the US WateReuse Research Foundation (now the Water Research Foundation), partly encouraged by the increasing severity of drought in California and the recognition that Australia and West Coast USA have each something to learn from the other. A range of AWRCoE “Water 360” educational and media products discussing recycled water for drinking have been adapted for use in California [86]. Links were also established with the South Africa Water Research Commission. Output from AWRCoE research may be found at the Water Research Access Portal [87].

The National Centre of Excellence in Desalination Australia (NCEDA) was hosted in Perth by Murdoch University, the other initial partners being Curtin University of Technology, Edith Cowan University, Flinders University, University of New South Wales, University of Queensland, University of South Australia, Victoria University, University of Western Australia and the Western Australian Water Corporation. Its priority research themes were Pre-treatment; Reverse osmosis desalting; Novel desalting; Concentrate management; and Social, environmental and economic issues. The NCEDA initiated 44 research projects. It completed a Pilot Scale Test Facility and Desal Discovery Centre to educate schoolchildren in Perth [88]. The Centre continued to function until September 2016, but efforts to secure subsequent funding through the Cooperative Research Centres program were unsuccessful.

Towards the end of the millennium drought, AWRCoE and NCEDA jointly funded the development of an interactive database of resilient water resources including recycled water and desalination plants [89]. The data were to be managed by the Australian Government’s Bureau of Meteorology through its annual collection of performance data from water utilities. The data for 2012–13 from 410 water recycling sites and 88 desalination sites showed a capacity of 1831 × 10^6 m³/yr and a production in that year of 410 × 10^6 m³. However, it has proved difficult to secure data from individual plants since then. The location of these sites and the interactive dashboard for resilient water resources is shown in Fig. 5. It will be noted that many inland desalination plants, though small, access saline groundwater for local community use.

6. 2010–2019: After the millennium drought – economics the new driver

The millennium drought came to a close in some areas at the end of 2008 when rains returned to north-eastern Australia. As Brisbane’s Wivenhoe dam was filling from catchments and no water had yet been added from the Western Corridor Scheme, there seemed no need to top up the dam. Standing at 70% full, the Queensland government determined that recycled water would be added in the future only if the Wivenhoe storage fell below 40% of capacity. The period from late November 2010 to mid-January 2011 was extremely wet through much of eastern Australia. There was widespread flooding including in downtown Brisbane. Its Wivenhoe dam, which also served as a flood attenuation dam, filled to 200% of its maximum water storage capacity. All the east coast desalination plants and advanced water recycling plants (Table 3) were virtually taken out of service once their validation and contract proving stages were completed. The Gold Coast Tugan plant was fleetingly reactivated when Cyclone Ostwald in 2013 dumped huge rainfalls on the Wivenhoe catchment, the subsequent massive silt load causing major problems for Brisbane’s Mount Crosby water treatment plant.

The end of the millennium drought in eastern Australia changed community, industry and government policy focus in strengthening the security of water supply (at almost any cost) to one of pursuing economic efficiency and containing consumers’ water charges and prices. The new driver was that of economics. Large government grants for infrastructure may have led to perverse outcomes. Most States/Territories had introduced independent economic regulators. Considerable criticism developed of how urban water supplies were secured and the extent of investment in alternative water sources. The costs to consumers and the community during and after the Millennium drought were large. Water restrictions were likely to have cost the nation in excess of a billion dollars per year from the lost value of consumption alone [90]. After the drought, attention turned to economics, particularly the debt loads that the alternative water source plants had generated, and the impact of perceptions and increased costs and prices on water consumers. Having signed the Intergovernmental Agreement on the National Water Initiative, governments had committed themselves to full cost recovery, including debt servicing. Supply augmentation in Melbourne and Perth, for example, could cost consumers and communities up to $4.2B over 20 years.

The Australian National Audit Office concluded that when considered against Commonwealth program guidelines, grants for the Adelaide Desalination Plant did not demonstrate satisfy the program’s merit criteria [91]. There were considerable differences in the capital costs and operating costs between each of the desalination plants and with the Western Corridor Advanced Water Treatment plants. When the plants are not in use, the costs of debt servicing and care and maintenance may still exceed half the total operating costs at full production [92]. The Victorian Auditor-General noted that over five years 2008–2012, interest bearing liabilities increased by 248%, with finance costs by then accounting for 21% of the Victorian water industry’s total operating costs [93]. Regulated prices were established for Sydney desalination plant after its private leasing, including for various periods of non-production and for start-up costs after a period of closure [94].
6.1. Comparative costs

Where possible, water supply systems are gravity-fed from reservoirs. Sydney, Melbourne, and South East Queensland normally have relatively low water supply costs because of the height of their major reservoir off-takes above their city supply areas. The water supplying Brisbane, South-East Queensland’s major city, is treated and pumped to homes for consumption at an energy cost of 0.67 kWh/m³. For the Gold Coast, the second largest SEQ city, the figure is a lower at 0.22 kWh/m³, by virtue of the large gravity head from the Hinze Dam and simpler treatment requirements [95]. By contrast, Adelaide has very high water supply pumping costs attributable to having to pump water from the River Murray over the Adelaide Hills to metropolitan reservoirs, representing 1.6 kWh/m³ [39]. In contrast to other capital cities, Perth is highly dependent on accessing groundwater.

Water recycling plants are generally at the lowest point of a water and wastewater distribution system while sea water desalination plants will be just above sea level, so both require pumping to supply the water produced. Saline groundwater plants will even require pumping to access the water resource before treatment. The energy cost of pumping is dependent on friction loss (a function of the pipe diameter, material roughness and distance) and lift involved. In the absence of losses, pumping one cubic metre of water for 1 m requires 0.0027 kWh of energy [39]. In Brisbane, the direct operating cost of producing manufactured water from the Gold Coast desalination plant in 2011–2012 was estimated at $959/10^6 m³; from the Advanced Water Treatment plants of the Western Corridor scheme $834/10^6 m³; while that harvested from the catchment base which had constituted 96% of Brisbane’s water, cost $67/10^6 m³ [96]. It is assumed, that the costs of maintaining the catchment environment or income foregone from alternative catchment uses were excluded from the catchment base calculation. The energy costs for water to the tap including pumping from the Western Corridor plants to the Wivenhoe Dam and then flowing down the Brisbane River for subsequent treatment at Mt Crosby have been estimated at 2.45 kWh/m³, from the raw water source to the consumers’ tap via the Tugun desalination plant at 4.30 kWh/m³ and raw water from Wivenhoe and the Brisbane River to the consumers’ tap via Mt Crosby water treatment plant at 0.40 kWh/m³ [97]. Submissions to a Queensland Parliamentary inquiry (now lapsed) suggested that the Western Corridor scheme would be much more economically effective if recycled water were piped directly as potable water to the Mount Crosby Water Treatment Plant rather than being pumped a considerable distance as a form of IPR to the Wivenhoe Dam and then flowing down the Brisbane River to Mt Crosby [98].

Inter-basin transfers may be regarded as an alternative water source. A small amount of water for agricultural use can represent a relatively large amount of water for urban users. However, apart from its pumping costs, it may involve considerable local community angst. One approach is to purchase water, redirecting it from agricultural users for urban supply. The South Australian Water Corporation as well as owning permanent water entitlements purchased from NSW and Victoria and transferred within the Southern Murray Darling Basin to South Australia, also purchased temporary (seasonal) allocations in 2008-9 and 2009–10 [99]. In Victoria, scope was provided for a substantial transfer of irrigation water with the Sugarloaf Pipeline, completed in 2010 for $750 M. It connects the Goulburn River to Sugarloaf Reservoir and was expected to supply 75 × 10⁶ m³ of water to Melbourne each year when in use. However, following considerable disquiet expressed by irrigators in the form of a “Plug the Pipe” campaign, the Victorian Government imposed a policy ban, determining that the pipeline is not to be used except in the

---

Fig. 5. Bureau of Meteorology Dashboard with map showing location of water recycling and desalination plants 2013 (89).
case of critical human need for water in metropolitan Melbourne [90].

The 90 × 10^6 m^3/yr capacity Sydney desalination plant operated from 2010 and used 257.7 GWh of power in its first and only full year of operation [48], representing an energy cost of 2.86 kWh/m^3. The plant was taken off-line in June 2012 when Sydney reservoirs were at 98% capacity. A fifty-year lease of the plant was sold by the Sydney Water Corporation on behalf of the NSW Government to a consortium of Ontario Teachers’ Pension Plan Board, The Infrastructure Fund and Utilities Trust of Australia with a buy-back water contract with Sydney Water. The contract provides for the plant to be brought back into operation if Sydney Water storages fall <60% and it will be mothballed again when storage rises >70%. The plant is operated by Veolia Water Australia, which has eight months to bring it into operation when requested. Pricing for the purpose and monopoly supply is set by the New South Wales Independent Pricing and Regulatory Authority (IPART). In January 2019, water levels fell <60% and by July 2019, the plant had been activated to full capacity [100].

In 2011, Sydney Water confirmed that it had no intention of building any further recycled water plants to serve domestic third pipe systems because they were too costly [101]. The Hoxton Park scheme, previously announced for 14,000 houses as one of 15 schemes to have been operating by 2015, is now seeking 6500 home owners to opt into scheme (4000 have already done so), with the result that recycled water might be flowing through the already constructed purple pipes by 2021 [102].

Despite Sydney Water withdrawing from dual piping systems to supply recycled water following the end of the Millennium drought, the City of Sydney which manages the Central Business District, developed a Decentralised Water Master Plan 2012–2030 for the City of Sydney area founded on the principles of integrated water cycle management [103]. Adopting the principle that sewage and stormwater are to be treated as a water resource rather than waste to be discharged, the City encouraged its adoption by private sector developers who were building new business and residential towers. Outcomes include Sydney Park, which hosts the City of Sydney’s largest stormwater harvesting system, recycling 0.85 × 10^6 m^3/yr. The Sydney Park wetlands will contribute to the 2030 targets for 30% of water demand being met through local water capture and reuse and a 50% reduction in suspended solids and 15% reduction in nutrients discharged to local waterways via stormwater run-off. Initially, the water will be reused to top up the wetlands and irrigate parks and subsequently reuse will expand to surrounding commercial, industrial and residential areas. The first major infrastructure project in Sydney’s Green Square is a new stormwater drainage system built in partnership with Sydney Water. The Barangaroo development of three office buildings and 1000 apartments includes a plant that can produce 0.2 × 10^6 m^3/yr of recycled water [104]. In regional New South Wales, Ballina became the first town to open a local purple pipe dual reticulation system [105] aimed to ultimately supply 7200 homes.

The 150 × 10^6 m^3 annual capacity Victorian Desalination Plant requires 90 MW of power supplied underground through a 220 kV high voltage alternating current power cable. The plant was built by a Public-Private Partnership with Aquasure which contracted to finance, build, maintain and operate the project for 30 years. Aquasure’s fixed price for construction of the whole project was $3.5B. The plant was placed into preservation mode after completion in 2012 until its power was reconnected in March 2017 to respond to its first 50 × 10^6 m^3 supply notice for desalinated water to be delivered between 1 July 2016 and 30 June 2017. A further order followed for 15 × 10^6 m^3. The plant returned to production in June 2017. Power consumption was offset with renewable energy certificates [106]. Due to drying climatic conditions, 125 × 10^6 m^3 of water has been ordered from the plant for 2019–2020, to prevent Melbourne’s storage spaces dropping to a point where they pose a significant risk to water security. This represents one quarter of Melbourne’s annual consumption [107].

Melbourne has three retail water companies which have continued to provide and extend recycled water, much of it for amenity use and agricultural and pasture irrigation. South East Water provides reticulated water to housing in Cranbourne, Clyde, Lyndhurst, Pakenham and Officer. City West Water has provision for recycled water to be provided to 6200 homes in Werribee, Wyndham Vale and Manor Lakes. The recycled water comes from Melbourne Water’s Western Treatment Plant at Werribee, though some drinking water may be included in recycled water lines. Homes in Vineyard Estates were to be added in late 2019. Yarra Valley Water has mandated recycled water in the development of Aurora Estate and Epping North East; Wollert; Craigieburn West; Croydon/Lilydale (Quarry development), Beveridge/Wallan, Greenvalle, Doncaster Hill and Kalkallo, the latter also incorporating stormwater and rainwater from the roofs of industrial buildings. Manuals are provided for developers covering the connection costs and building requirements for the inclusion of recycled water in new housing and industrial developments [108].

A large specific purpose water recycling plant, located underground for aesthetic reasons, is in Yarra Park adjacent to the Melbourne Cricket Ground (MCG). It was funded by the Melbourne Cricket Club (MCC) ($18 M) and Victorian Government ($6 M). It treats sewage from the local sewerage network to Class A recycled water standards (Table 1). The treatment train consists of screening and grit removal, biological treatment of the sewage and coagulation for phosphate removal, filtration via membrane bioreactor and ultra-filtration membrane systems, before final disinfection via ultraviolet and chlorination. More than 180 × 10^6 m^3 of recycled water is produced annually, reducing the MCC’s use of potable water by 50%. The water is primarily re-used as irrigation in Yarra Park, as well as for cleaning and toilet flushing at the MCG and at nearby Punt Road Oval [109].

In South-East Queensland, the Gold Coast Desalination Plant was retained in ‘hot standby’ condition after completion, able to provide 33% production capacity within 24 h and full capacity within 72 h. It has been operated to meet demand when other local Water Treatment Plants are off-line for maintenance or planned upgrades, and during severe weather events [110].

Brisbane’s Western Corridor Scheme involving three WWTPs was almost totally decommissioned in 2012 and the remaining infrastructure placed in care and maintenance until the Wivenhoe storage fell below 40% capacity [111]. A detailed review of the development of this scheme has been undertaken [112]. Modelling indicated that there would be <5% chance of the key water storages falling to the 40% trigger within the next 15 years. The microfiltration and reverse osmosis membranes were discarded from most treatment trains except two used to produce recycled water for use in the Luggage Point plant. It has been estimated that it would take up to two years to bring the scheme back on-line [113]. Planning for this process was initiated in 2018.

However, the Gold Coast City Council resolved on 12 December 2013 to discontinue the supply of recycled water to 6700 houses provided with dual reticulation systems in Pimpama-Coomera by mid-2017. After considering costs to operate and maintain the recycled water network, the then current and future recycled water and potable water demand and the infrastructure yet to be installed by the Council, home-site developers and home owners, it was concluded that the high cost of the Class A+ recycled water scheme for the City and the Gold Coast community outweighed the value to the city [114]. This is the only known case of a dual pipe supply system being abandoned in Australia, though there are other examples where completed dual supply systems have yet to be supplied with recycled water [115].

In South Australia, following acceptance, the Adelaide 100 × 10^6 m^3/yr desalination plant was not operating at 10% of its production capacity, all the production banks of reverse osmosis membranes being maintained by regular operation in rotation. The plant was operated at 100% capacity for a few hours on a monthly basis. It was assumed that only a small amount of water would be drawn from the Adelaide Desalination Plant due to its high operating and energy costs, so the plant was to work primarily as a backup supply during drought years with low rainfall and/or high demand. The Mount Lofty Ranges catchments are generally the preferred source for the potable water supply for Adelaide due to their
low cost and energy demand, followed by the River Murray, even though pumping over the Mount Lofty Ranges is required. In 2019, SA Water sold some of its River Murray water allocation as a temporary transfer to the Commonwealth Government which wished to assist struggling droughted Victorian dairy farmers by providing more water for growing fodder for their stock [116]. Effectively, the Commonwealth water purchase underwrote the costs of producing 100 × 10^3 m^3 of desalinated water for Adelaide. The transaction demonstrated a win-win outcome by using the water trading provisions in the National Water Initiative.

Adelaide has also seen a continuation of dual piping systems in new subdivisions. South of the city, the recycled water from the Christies Beach WWTP has been extended to Seaford Heights, while the north-eastern suburb of Lightsview has been reticulated by Lightsview Rewater, a private sector subsidiary company owned by Water Utilities Australia Pty Ltd, using water from the Salisbury Water Company’s MAR scheme. MAR has been widely adopted in Adelaide following its initial introduction by the Salisbury Council from the 1990s. By 2017, there were 58 MAR schemes in the Adelaide metropolitan area involving harvests between 1 × 10^3 m^3/yr and 1 × 10^6 m^3/yr. Ten local government councils, a private company and the South Australian Water Corporation have been involved in the separate schemes, for which 750 km of reticulation piping has been laid [117].

A solar thermal power plant driving seawater desalination was established in 2016 as part of the innovative business of Sundrop Farms in arid northern South Australia near Port Augusta. This takes seawater, for multiple effect distillation, generates up to 39 MW of power with an array of 23 000 solar heliostats, produces 450 × 10^3 m^3 of fresh water which is used to grow 17 000 tonnes of tomatoes in a 0.2 km^2 hydroponic greenhouse complex [118].

In April 2018, a major $155.6 M expansion of the Northern Adelaide Plains irrigation area was commenced. A project, independent of the Virginia Pipeline Scheme commenced twenty years earlier, is to provide an additional 12 × 10^6 m^3 of recycled water from the Bolivar WWTP to be distributed through a new 28 km water main and distribution infrastructure north of the Gawler River to underpin an economic development initiative for large-scale advanced glasshouse horticulture, nurseries, floriculture, protected orchards and vine crops, premium irrigated field crops, feedlots and intensive poultry businesses. This initiative has clearly identified economic development as a further driver for introduction of recycled water and incorporates local expertise in the use of MAR as a management tool within the water cycle.

The end of the millennium drought in the rest of Australia had little impact in Western Australia which had long recognised the early signs of climate change. Its two desalination plants were retained operating at full capacity while the development of groundwater replenishment for Perth, described earlier, was continued.

6.2 Governance changes

At the national level, following the end of the millennium drought, priorities had turned away from water. Intergovernmental and statutory institutional structures were abolished. The mandate of the Standing Council on Environment and Water which had been responsible for coordinating Commonwealth/States/Territories water policies was revoked on 13 December 2013 [119]. The National Water Commission, responsible for driving water reform in Australia, was effectively closed as a budgetary saving from 31 December 2014 [120]. Water policy complacency became evident and reform impetus was being lost, though a National Water Reform Committee is still undertaking work to identify national water reform priorities. A Productivity Commission review identified that backsliding against early reform commitments had occurred, with some governments appearing to have forgotten the reasons for agreeing to water reforms and taken for granted the benefits they generated. Urban water reform was perceived to need further development. It was suggested that water entitlement frameworks should be amended to enable inclusion of recycled water and stormwater to facilitate their use in situations such as MAR and streamflow enhancement [121]. The need to again have an independent agency overseeing continued progress with water reform policies was recognised by the nation’s independent infrastructure advisor, Infrastructure Australia, [122]. It has also been noted that water research funds, which had never had any recurrent base, were reducing [123].

However, during the post-millennium drought period, the various state-owned water utilities had been quietly improving their technical and energy efficiency in response to increasing energy costs and aspirations to achieve greenhouse gas reductions. Hydro-electricity systems were included in water reservoirs and sewage effluent and marine saline outfalls. Mini-hydro plants were added to trunk water lines and biogas from digesters was controlled and utilised for power generation. Some sewage plants with large land curtilages or pond surfaces used them for installing solar-voltaic arrays. Despite the increasing power demands of utilities from wider production of “manufactured water” from recycling or desalination, some WWTPs became net energy exporters [48].

The total volume of recycled water produced from WWTPs in 2017–18 by major urban utilities reporting to the Bureau of Meteorology was 151.7 × 10^6 m^3 compared to 137.2 × 10^6 m^3 in the preceding year. The annual figures from 2013 to 14 to 2017–18 (Table 5) showed considerable seasonal variation between years in consumption of recycled water reported to the Bureau in table W26 of its Annual Performance Report [124].

6.3. The future for direct potable recycling

Following the drought, the future adoption of direct potable recycling (DPR) was explored. The Australian Academy of Technological Sciences and Engineering (ATSE) concluded that advances in the science and engineering of water treatment, and recent international developments in DPR prompted consideration of DPR as a potential future component of Australian water supply systems. The potential obstacles or disadvantages for DPR, relative to IPR, were primarily related to public perception and acceptance. Importantly, ATSE considered that the scientific and engineering hurdles to implementing safe and reliable DPR were manageable. However, technical issues relating to the functions of an engineered buffer in DPR would need to be addressed to the satisfaction of the general community. Key among these issues is the need to ensure reliability. It was apparent from a review of Australian legislation and regulations that existing frameworks for planning, approval, management, and oversight of drinking water quality and recycled water in Australia could accommodate a well-designed and operated DPR project as a water resource management option. Advanced risk assessment and risk management tools were now available which could be considered for the implementation of DPR projects, relative to more established or conventional water sources [125].

Water Research Australia had identified rapid progress in the development of new potable reuse projects, as well as the governance and regulatory structures required to support them in international locations. In order to ensure that Australian water managers and decision makers were well informed of these developments, it commissioned a timely and technically robust update on developments in potable recycling to include a summary of key developments and current status of potable reuse practice and an understanding of the drivers and incentives which have underpinned this progress. The update included an overview of recently produced guidelines and best practice documents, and how international and Australian regulators had approached the regulation of potable reuse for the full protection of public health. It was concluded that the incentives for potable reuse – as for any water supply option – will ultimately lie in how the various available water supply options compare among key criteria, such as costs, environmental impacts and social considerations. These are highly geographically specific considerations and thus different conclusions can be expected to be drawn by different cities. Nonetheless, there is ample evidence to observe that some cities have identified planned potable reuse as an attractive water...
Table 5  
Total recycled water supplied ($\times 10^3$ m$^3$) from major urban centre water utilities between 2012-13 and 2017-18 - Bureau of Meteorology Annual Performance Report 2017-18 [124].

<table>
<thead>
<tr>
<th>Major urban centre</th>
<th>2013-14</th>
<th>2014-15</th>
<th>2015-16</th>
<th>2016-17</th>
<th>2017-18</th>
<th>Change from 2016 to 17 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>25 515</td>
<td>29 177</td>
<td>28 481</td>
<td>21 316</td>
<td>25 564</td>
<td>+25</td>
</tr>
<tr>
<td>Canberra</td>
<td>4372</td>
<td>4352</td>
<td>4053</td>
<td>33 210</td>
<td>30 296</td>
<td>−10</td>
</tr>
<tr>
<td>Darwin</td>
<td>347</td>
<td>492</td>
<td>80</td>
<td>541</td>
<td>451</td>
<td>−17</td>
</tr>
<tr>
<td>Melbourne$^a$</td>
<td>27 890</td>
<td>36 428</td>
<td>34 892</td>
<td>32 442</td>
<td>42 085</td>
<td>+30</td>
</tr>
<tr>
<td>Perth</td>
<td>10 029</td>
<td>9354</td>
<td>10 212</td>
<td>9569</td>
<td>12 100</td>
<td>+26</td>
</tr>
<tr>
<td>SE Queensland$^b$</td>
<td>23 082$^c$</td>
<td>18 774$^d$</td>
<td>19 822$^e$</td>
<td>14 755</td>
<td>13 056</td>
<td>−12</td>
</tr>
<tr>
<td>Sydney</td>
<td>46 943</td>
<td>43 075</td>
<td>34 324</td>
<td>38 340</td>
<td>42833</td>
<td>+12</td>
</tr>
</tbody>
</table>

Data for 2016-17 and earlier years were sourced from last year’s published report since definitions changed for 2017-18.  
$^a$ Melbourne and South East Queensland figures are the aggregated figures for the bulk utility and retailers.  
$^b$ Redland City Council did not report against the indicator in 2013-14.  
$^c$ Seqwater did not report against the indicator in 2014-15 and 2015-16.

supply option, based on considerations of criteria including water supply availability, costs and energy consumption. By international standards, the water quality regulatory landscape in Australia was widely considered to be world-leading. Potable water reuse is not held up by a lack of technical ability to build and design effective schemes, but potentially by other less technical aspects. The authors noted the WHO statement that “the ability to gain public confidence and trust through a productive, two-way engagement process with key stakeholders” is central to the success of any potable reuse project. To plan for safe, sustainable and affordable water supply systems of the future, Australia needs a national strategy for urban management, supported by an appropriate national body tasked with responsibility for overseeing implementation and suitably funded to meet this responsibility. Recognising the water industry’s aging workforce, a strategy for increased skills and competence assurance for advanced water treatment processes should be developed. Long-term community engagement strategies should be developed. Urban Water Planning Principles should consider the full portfolio of water supply and demand options [126].

The peak organisation for Australian urban water utilities, the Water Services Association of Australia (WSAA), also recently entered the field of reviewing the use of potable water recycling. It aimed to bring together world-wide insights and perspectives regarding community engagement on purified recycled water. The report recognises that purifying recycled water for drinking is becoming commonplace across the globe. Some 35 cities now rely on it (many for decades), and many more are looking at it. The report aimed to assist in the consideration of engagement strategies around the introduction of purified recycled water, encompassing both IPR and DPR [127].

Perth has been used as an example where IPR is already accepted, to discuss the scope to move onward with DPR. In doing so, the approaches in two US cities have been contrasted in determining the storage time in an engineered buffer (which might equate to an IPR environmental buffer) before addition into the drinking water system. San Diego, with a history of rejection of recycled water, has adopted an environmental buffer (which might equate to an IPR and DPR [127].

Perth has been used as an example where IPR is already accepted, to discuss the scope to move onward with DPR. In doing so, the approaches in two US cities have been contrasted in determining the storage time in an engineered buffer (which might equate to an IPR environmental buffer) before addition into the drinking water system. San Diego, with a history of rejection of recycled water, has adopted an environmental buffer (which might equate to an IPR and DPR [127].

...
of the eastern Australia coastline. As a result, the Warragamba Dam, Sydney’s main catchment resource, increased from 43% capacity to 82% capacity, representing nearly $800 \times 10^6 \text{ m}^3$ in about one week (Fig. 7) while the Wivenhoe dam serving Brisbane rose from 43.5% to 51.7% and Brisbane’s total water storage rose by 12%.

8. Discussion and conclusions

8.1. The environmental driver

Water recycling in Australia has been driven by a succession of policy drivers. Initially, recycling for alternative uses was the driver in response to the imposition of environmental composition restraints of effluent discharges from WWTPs to receiving waters. This led to redirection for use in agriculture with benefits from plant nutrients in the effluent stream, and in other cases for industrial use where drinking quality water was not required. Often the recycled water offered was priced very low to encourage its uptake, the cost of producing it being largely borne by the water utility’s retail customers as a necessary expense of meeting or avoiding discharge requirements. The increased environmental awareness and the introduction of policies governing competition (though water provision is largely a natural monopoly) encouraged the development of water quality guidelines and the introduction of a policy framework for use of water in Australia via the Intergovernmental Agreement on the National Water Initiative.

8.2. The continuity of supply driver

The Millennium drought resulted in a new driver of ensuring continuity of supply and led to seeking a diversity of water sources. In a threat of failing water shortages and the need to conserve remaining supplies of drinking water or even underpin drinking supplies, wastewater recycling was introduced. However, in no location was recycled wastewater ultimately used to augment drinking water before the drought broke. The potential water shortage crisis did lead to building numerous plants to recycle sea water, though after plant acceptance and validation, only in Perth was the potential for desalinated water immediately delivered into the drinking water system. The response to the drought did demonstrate Australia’s capacity to plan, develop and build quickly, major water recycling infrastructure in the face of a potential crisis. But the Millennium drought also demonstrated that while drought encourages adopting recycled water, the breaking of the drought allows its deferral or rejection and can result in policy complacency.

![Fig. 6. Towns in New South Wales and South-East Queensland with insecure water supplies as at 15 February 2020 - adapted from Page and Marinoni [131].](image-url)
8.4. The technical driver

The question also arose as to how to physically manage the plants when there was little or no demand for the produced water. All depended on membranes for their operations. There was only limited experience in their management when not in use. Ultimately, most of Brisbane’s Western Corridor Scheme was shut amid political rancour by a subsequent incoming government that regarded the scheme as a “white elephant”. Membranes were disposed of from their casings, noting that there was no standardisation of membranes between the three Advanced Water Treatment Plants. An estimate of two years was determined to reinstate the plant if it became necessary. The Gold Coast and Adelaide desalination plants were kept fully operational by running the plants at low level, rotating the treatment trains in use. The Sydney and Melbourne desalination plants were put in preservation mode after construction.

Water utilities have difficulty in determining how to manage their demands for alternative water sources compared with their surface water catchment supplies which are in dams already built with the capital costs likely “sunk” and represent the cheapest sources of bulk water. As well as economic judgements, technical judgements must be made about managing membrane plants, whether to have them contributing to base water supplies or as drought insurance. Risk assessments will be required about the probability of conventional water sources again becoming available. Risk assessments will also be needed in considering whether production systems for “manufacturing water” may become obsolescent and replaced by newer technologies within the asset life of technologies that have been adopted.

In the next decade, particularly if drought continues in the short term, thought will need to be given to addressing the need for alternative water supplies in remote and regional Australia, especially in New South Wales and Queensland where local government-managed water utilities have prime responsibility for supply. This may involve water recycling, saline groundwater desalination, and recourse to MAR for strategic storage when immediate access is not required. This may provide the opportunity for introducing new WWTP technologies which include potable water production as a component of base water supply. A variety of trains are becoming available [134]. Some have relatively small footprints, such as the use of membrane bioreactors. The portable potable water plant developed at the Self’s Point WWTP in Hobart for use in the Antarctic [84] is a good example of the potential for such plants for small rural areas. However, as higher technology plants are established by regional utilities, there will be a greater need for additional trained operatives [126] to supplement the consultants now accessed.

Non-membrane technologies may have a wider role in the future. As an example, research has been published on requirements for additional treatment to be used if wetland-managed aquifer recharged storm water purveyed by the Salisbury Water Company were to be made suitable for addition to the drinking water supply [135].

It is difficult to determine the future of dual pipe systems. They appear to have a continuing adoption in high rise office and apartment buildings and with their own self-contained WWTPs and recycling facilities in house where water is managed by a single entity. (The cost of dual plumbing systems has been estimated to increase plumbing capital costs in buildings over seven stories by only 9% [136].) Sydney Water is only slowly progressing recycled water in those to which it expressed enthusiastic commitment ten years ago. The risk of cross connection remains a concern, and identification may take a long time after an original connection had been inadvertently approved. An example took eight years to be detected in a family home at Mawson Lakes, South Australia before being corrected. The concluding observation was that the family’s health had not been at risk as the recycled water provided met Australian drinking water guideline standards from a health perspective, but not from a water aesthetics perspective [137]. It may well be that where

8.3. The economics driver

Following the end of the drought, capital city utilities were left with large pieces of recycling kit that was more expensive to operate than accessing their available catchment water again. The recycling plants had incurred a high capital cost, the debts of which still had to be serviced. These costs resulted in increased water utility bills for customers, though in some cases these were controlled by extending debt repayments over longer time frames so that the annual costs became less, even though the total combined debt and interest repayment exceeded those originally budgeted. Economics became the next driver in the potential use of recycled water. The New South Wales government, though Sydney Water Corporation, sought to recoup debt for its desalination plant by leasing it for 50 years with an associated contract to pay the annual resting maintenance costs and the production initiation and operating costs when water was required. The Melbourne desalination plant was constructed by a public-private partnership with operating rights for 30 years. The operation of most large water recycling and desalination plants was contracted out to private service providers by the state-owned water corporations.

Fig. 7. Warragamba Dam capacity February 25 2020 – (Bureau of Meteorology Water Storage App version 2.0.0.bld).
reycled water is to be used in an urban area adjacent to a WWTP, it may be cheaper to process it to direct potable standard to augment existing drinking water supplies rather than having the cost of a suburb-wide dual piping system and its additional risks and maintenance costs.

8.5. The broader picture

The future of water planning, management, wastewater treatment and water recycling needs to brought within the compass of a broader picture that encompasses the role of integrated water cycle management and the role of water in urban amenity, including offsetting increasing urban heat island effects in cities from climate change, the more effective integration with urban planning and the achievement of biodiversity conservation objectives. These policy decisions are often set without clear and transparent evidence and analysis [138].

8.6. Community acceptance

An important component of managing the introduction of new technologies to achieve greater diversity of supply is how the community is brought into the communication and decision-making process, an issue raised in the development of many recycling proposals. Most of the large schemes developed in response to Australia’s millennium drought were conceived and constructed in short time frames with limited public consultation. Several produced opportunities for political posturing for or against the proposed infrastructure with opportunistic political grandstanding. The difficulties experienced in communication in Queensland contrast with those used in Singapore and Orange County [139] and in Perth. Although there have been three major reviews of DPR issues for Australia in the past half-decade, their consideration has been largely among water professionals. The debate over recycling domestic household waste into three or four streams encompassing combined food and garden organics, glass, combined paper, plastic and metals, and separate residual waste has generally been won among the urban community. The necessary debate about water recycling has yet to be embraced with the consuming public. The AWRCoE “Water 360” information package on potable recycling, though used in California, has seen little use in Australia, where it has been transferred to WSAA [140]. That debate needs to be gently started, so that if potable water recycling is introduced in a future drought-driven water crisis or in response to Australia’s burgeoning population increase in an inherently dry country, the consumers will be comfortable with such an approach.

As the early 2020 dry record conditions in some parts of Australia meant that as the community was focused on water, it could be a good time for conversations about long-term supply options. WSAA emphasises that no decisions have been made to pursue purified recycled water in most Australian states, apart from Western Australia and the Western Corridor scheme in South East Queensland (currently off-line), though the Orange City Council (NSW) operates another example of IPR, albeit using stormwater rather than advanced wastewater recycling. Good water industry planning involves looking at all the water supply options as agreed in the National Water Initiative. The experiences of overseas utilities provide a positive framework while highlighting the importance of bringing the community to confident acceptance. Yet attention to water issues must not be allowed to be overtaken by even more recent events such as bushfires or pandemics. Australia needs water for its long term economic and social success.

Novelty statement – Radcliffe and Page paper

Australia began adopting recycled water in the early 1990s, accompanied by the first quality standards. Progress was driven by the imposition of discharge standards from WWTPs, then by the millennium drought when all states developed recycling and desalination projects to diversify water sources for urban and agricultural use. Economic reflection followed the end of the drought. Indirect potable recycling is being adopted, but community debate on direct potable recycling has yet to be held.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The constructive suggestions of Dr Graham Bonnet and two anonymous referees are gratefully acknowledged.

References


ABBREVIATIONS

$": Australian dollar (AUD), not inflation corrected
ACT: Australian Capital Territory
ACTEW: ACT water utility
AWRCoE: Australia and New Zealand Environment and Conservation Council (Ministerial level)
BRM: Biological Nutrient Removal
BOD: Biological Oxygen Demand
CAPE: Citizens Against Drinking Sewage
CSIRO: Commonwealth Scientific and Industrial Research Organisation
DAPF: Dissolved Air Flotation Filtration
DFA: Disability Life Years
DPF: Direct Potable Recycling
enHealth: Environmental Health Committee of the Australian Health Protection Committee
GL: Gigalitres (10^9 m^3)
IDEA: Interministerially Deemed Extended Aeration
IFS: Integrated Fixed-film Activated Sludge
IPART: New South Wales Independent Pricing and Regulatory Authority
IPR: Indirect Potable Recycling
kL: Kilolitre
kW/m^3: kilowatt hours per cubic metre (rate of power consumption)
M: million (10^6)
mg: milligram
m^3: cubic metre
MBR: Membrane Bioreactor
MF: Microfiltration
mg: milligram
mg/L: milligram per litre
ml: millilitre
mm: millimetre
NCDIA: National Centre of Excellence in Desalination Australia
NIMHRC: National Health and Medical Research Council
NSW: New South Wales (state)
NT: Northern Territory
NTU: Nephelometric Turbidity Unit (measure of turbidity)
NWC: National Water Commission
NWQS: National Water Quality Management Strategy
Pty. Ltd.: Proprietary Limited (a company in which the shares are held privately)
Q: Queensland (state)
QPFA: Queensland Environmental Protection Agency
RA: Reverse Osmosis
SA: South Australia (state)
STEPS: Septic Tank Effluent Drainage Scheme
TDS: Total dissolved solids
US: United States of America
UV: ultra-violet
Vic: Victoria (state)
WA: Western Australia (state)
WHO: World Health Organisation
WSAA: Water Services Association of Australia (peak organisation for major water utilities)
WWT: Wastewater Treatment Plant

40