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A History of Wastewater Irrigation in Melbourne, Australia

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ABSTRACT

Reclamation of wastewater for irrigation has had an important role to play in Melbourne's struggle to manage water resources as effectively as possible. Rapid growth within the first few years of the founding of the city led to a sanitary crisis, which provided the impetus for the construction of a large sewerage system. Interest in using the effluent from sewage treatment plants for irrigation gained attention in the late 1970s, but despite some activity in the early 1980s, it was not until 2005 that large-scale wastewater irrigation schemes became a reality. Successful to a degree, there have also been problems, and the future viability of one large irrigation scheme for commercial vegetable production is threatened by high salt concentrations in the treated wastewater. Greywater irrigation at the household level has also become commonplace in Melbourne over the last decade, but it is difficult to regulate and the health risks urgently need to be quantified. More recently, several third-pipe schemes, where treated wastewater is reticulated to households, have been commissioned with plans for many more, and treated stormwater is growing in popularity, particularly for irrigation of public open spaces.

Keywords: Graywater; Greywater; Reclaimed water; Recycled water; Reuse; Vegetable

1. INTRODUCTION

Water scarcity is a serious economic threat in Australia. As the world's driest permanently inhabited continent, and supporting a population of nearly 23 million people, there are significant challenges to ensure reliable, quality water supplies for agricultural, industrial and domestic uses. Melbourne, the capital of the State of Victoria in the south-east of the mainland, has arguably felt the strain of water scarcity stronger than any other Australian city. Receiving only 639 mm of rainfall annually and experiencing hot summers (Bureau of Meteorology, 2011a), it is among Australia's driest cities but it is also one of the largest, with a population of 4.1 million (ABS, 2011). To place Melbourne in perspective one need go no further than Sydney, which is of a similar size (4.6 million) yet receives almost twice the annual rainfall (1302 mm), while Adelaide has slightly less annual rainfall (549 mm) than Melbourne but a population just over a quarter the size (1.2 million), and Perth has higher rainfall (819 mm) at less than half the size (1.7 million) (ABS, 2011; Bureau of Meteorology, 2011a).

The use of treated wastewater, both sewage and greywater, has had an important role to play in helping Melbourne improve its water security, particularly in the last decade. It has not been a simple journey though and there is still a long way to go to ensure wastewater reuse for irrigation achieves its full potential in Melbourne. Starting with the development

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of its sewerage system, which provided the infrastructure necessary for coordinated wastewater irrigation schemes, and moving through to the use of greywater and treated sewage at households, we trace the history of wastewater and its use for irrigation in Melbourne (Table 1). Mistakes have been made and opportunities missed along the way, and the long-term sustainability of wastewater irrigation is far from certain. Rather than present Melbourne as an exemplar, we hope that the positive and negative lessons alike will be useful for other cities around the world, as attention to wastewater as a resource continues to increase globally (Hamilton et al., 2007; Jiminez and Asano, 2008).

Table 1 Chronology of events pertinent to the development of wastewater irrigation, Melbourne[a]

Year(s)	Historical Events
1847	Melbourne officially declared a city by HRH Queen Victoria on 25 June
1853	The Board of Commissionaires of Sewers and Water Supply established
1888	Royal Commission into Melbourne's human waste disposal recommends construction of waterborne sewerage system
1891	Establishment of Melbourne and Metropolitan Board of Works (now known as Melbourne Water) to oversee construction and management of sewerage system
1895–1902	Federation Drought
1897	Melbourne's sewerage system and Werribee Farm (WTP) begin operation
1901	Federation of Australia
1914–1915	Drought
1937–1945	World War II Droughts
1965–1968	Drought
1972–1973	Short drought
1973	Establishment of Standing Committee on Water Supply for Victoria, with sub-committee on wastewater reuse. Overseas study tour to investigate reuse of wastewater
1975	South Eastern Purification Plant (ETP) begins operation
1977	Wastewater irrigation study at the Victorian Government's Frankston Vegetable Research Station commences (finishes 1983)
1977–1978	Victorian Government legislates use of wastewater reuse through the *Health (Amended) Act 1977* and the *Health (Use of Waste Water) Regulations 1978*
1981	First official use of treated wastewater from ETP for agricultural (vegetable) irrigation
1982–1983	Short but Sharp Drought, followed by a giant dust storm in Melbourne and the Ash Wednesday bushfires
1983	*Guidelines for the Disposal of Wastewater on Land by Irrigation* Stage 6 water restrictions in Melbourne (Melbourne Water, 2012)
1989	Victorian *Water Act 1989*
1991–1995	Long El Niño Drought
1991	*Guidelines for Wastewater Irrigation*(EPAV, 1991)
1994	Council of Australian Governments (CoAG) water reform framework (CoAG, 1994)
1996	*Guidelines for Wastewater Reuse* Report from Port Phillip Bay Environmental Study published recommending 1,000 tonne nitrogen load reduction, of which half was to come from WTP
1997	*National water quality management strategy. Guidelines for sewerage systems: effluent management*
2000	*National water quality management strategy. Guidelines for sewerage systems: reclaimed water*

Year(s)	Historical Events
2002–2010	Millennium Drought
2002	Senate inquiry into urban water management in Australia
	Guidelines for Environmental Management: Disinfection of Treated Wastewater
	Victorian government announces target to recycle 20% of Melbourne's water by 2010 (DNRE, 2002)
	Household water restrictions applied – first time in 20 years (Melbourne Water, 2011a)
2003	Ban on pumping from aquifer at Werribee for remainder of irrigation season
	Guidelines for Environmental Management: Use of Reclaimed Water
2004	Installation of activated sludge plants and other plant upgrades at WTP to meet new EPA discharge targets
	Victorian Government White Paper and National Water Initiative
2005	Growers in the Werribee Irrigation District (WID) begin to receive treated wastewater and Eastern Irrigation Scheme (EIS) comes online.
	Guidelines for Environmental Management: Dual Pipe Water Recycling Schemes – Health and Environmental Risk Management
	Permanent Water Saving Rules established
2006	*National guidelines for water recycling*
	First major crop failure event in WID, presumed to be linked to wastewater, but investigation inconclusive
2007	Commonwealth *Water Act 2007*
	Ban on pumping from aquifer at Werribee (ban remains active) and domestic water restrictions strengthened
2008	Second major crop failure event in WID, presumed to be linked to wastewater but cause inconclusive
	'Target 155' initiative launched
2009	Aurora residential development opens: Melbourne's first designed residential scheme to use treated wastewater
	Black Saturday bushfires
2010	Water restrictions eased and storages at 40%
2011	Desalination plant scheduled for completion by end of 2011

[a]Refer to citations in the text.

2. MID 19TH CENTURY TO 1960s: TYPHOID'S LEGACY

Officially declared in 1847, Melbourne is a relatively young city by world standards. It got off to a flying start though. Victoria was made a Colony in its own right in 1851 and Melbourne was the clear choice for its capital (City of Melbourne, 1997). By the end of that year, gold was discovered at Anderson's Creek (30 km NE of Melbourne's centre and now part of suburban Melbourne), and Clunes and Buninyong (near Ballarat, ~100 km WNW) (Stawell Historical Society, 2002). This was one of the largest gold rushes the world had ever seen, and prospectors from across the globe descended on Melbourne in the hope of making their fortunes. The Gold Rush immediately transformed Melbourne into a prosperous and populous city (Museum Victoria). Astonishingly, in the 10 years following discovery of gold, the population increased fourfold and by 1861 Melbourne's population exceeded that of Sydney (Cambridge University Press, 2005). The wealth generated from the rush financed major development in the city, made it one of the world's wealthiest cities (Cambridge University Press, 2005) and ultimately earned it the proud moniker 'marvellous Melbourne'.

The two basic needs of any city, sanitation and clean, reliable water supply, clearly needed to be reassessed in the face of such rapid growth. To this end, the Board of Commissionaires of Sewers and Water Supply was established in 1853 (Heritage Victoria, 2007). As the name implies, its brief was to ensure Melbourne's sanitation and water supplies were adequate. The latter was tended to almost entirely through the construction of Yan Yean Reservoir in 1857.

Action on the sanitation front, on the other hand, was much slower. From the 1850s through to the 1880s, Melbourne did not have a sewerage system, i.e., a network of sewers conveying sewage to a central location for treatment and/or disposal. Rather, toilets comprised a bucket in a small shed, known as a 'thunderbox' or 'pan closet'. This was emptied only once a week, with a nightman and his cart collecting the waste under the cover of darkness (Melbourne Water, 2011b). These faeces were often taken to market gardeners as crop fertiliser; Melbourne City Council made £2298 from the sale of its nightsoil in 1898—nearly as much as proceeds from the sale of fertiliser (blood and bone) from City abattoirs ((Government of Victoria, 1898) in (Gaynor, 2006)). Residents would dispose of other household waste, including the contents of chamber pots, into open drains that ultimately discharged to streams and the Yarra River, the major river running through Melbourne. Owing to the unpleasantness and inconvenience of visiting the thunderbox in the night, chamber pots were also used for defecation, and consequently faecal contamination of waterways was becoming a serious problem. Toilet buckets that were emptied only once a week, coupled with faecal pollution of streams, not only raised significant public health concerns, particularly typhoid (Troy, 2008), but were damaging Melbourne's reputation, which had earned a new moniker: 'marvellous Smellbourne'. Something had to be done. A Royal Commission was held in 1888 to attack the problem and the solution proposed was simple—build a sewerage system (Melbourne Water, 2011b). The following year the English engineer James Mansergh was charged with making it happen. In the report outlining his proposal, he stated that the sewers should '...take all the water passing through WCs, lavatories, baths and urinals, all chamber slops, water used in cooking, washing, food, clothes, floor &c., and generally from sinks in kitchens, cellars and sculleries, from stables, cowhouses, &c., and from washing of paved yards...' (Mansergh, 1890). This was to be a water-borne sewerage system that did it all. Mansergh's scheme involved two treatment plants, one at Werribee (35 km SW of Melbourne) and one at Mordialloc (25 km SE) (Penrose, 2001) (Figure 1). In 1891 the Melbourne and Metropolitan Board of Works was established, primarily to oversee the construction and management of Melbourne's sewerage system (Melbourne Water, 2011a). They simplified Mansergh's proposal to just one plant, at Werribee (Penrose, 2001). The plant was originally known as the Metropolitan Farm and has informally been called the Werribee Farm; its current name is the Western Treatment Plant (WTP) and for convenience we will refer to it as such henceforth.

A Melbourne-wide sewerage system could not come quickly enough, putting an end to the regular wave of typhoid epidemics that killed Melburnians throughout the late 1800s. There were two multi-year epidemics in the 1860s and a renewed epidemic in the 1870s that killed about 4000 people. By 1878, things had gotten so bad that the death rates were 300–400 per cent higher than the worst British towns of Croydon, Glasgow and Paisley ((Thomson, 1879) in (Smith, 2002)). Following the first connection of homes to Melbourne's sewerage system in 1897 (Melbourne Water, 2011b), there was a steady decline in typhoid mortality. By 1915, 138,108 households were connected and the cases of and deaths from typhoid fever had declined by more than 90% (Laughton, 1916).

The first sewage flowed into the WTP in 1897. Melbourne now had an organised sewerage system with a large sewage treatment plant—one that still treats 54% of Melbourne's sewage (Steele et al., 2006). Three different systems have been used to treat sewage at the WTP: land filtration, grass filtration, and lagoon treatment (Melbourne Water, 2011b). Land filtration dates back to 1897 and was the main treatment method during summer. Open paddocks were flooded with sewage to a depth of 10 cm, and the soil acted as a filter with the remaining liquid flowing into an earthen drain at the end of the paddock. Grass filtration was adopted in the 1930s as the main winter treatment. After primary sedimentation, the sewage slowly flowed over sloping bays planted with flood-tolerant grasses. The first treatment lagoons were constructed in 1936 and, unlike land and grass filtration, are used throughout the year. Lagoons have been continuously upgraded over the years and the first large modern lagoon was installed in 1986. Both land and grass filtration methods have been phased out and all sewage is now treated in the modern lagoons.

By the 1960s though, it was apparent that another treatment plant was needed (Melbourne Water, 2011b). This plant was to be located SE of Melbourne, and, ironically for Mansergh, the selected site was only 15 km from Mordialloc. The Eastern Treatment Plant (ETP, formerly the South Eastern Purification Plant), built on 1100 ha, would open in 1975, treating sewage from Melbourne's eastern and south-eastern suburbs (Melbourne Water, 2010).

Melbourne now had an extensive sewerage network and two large wastewater treatment plants—both adjacent to valuable peri-urban market gardens. This fortuitous co-location of supply (treated wastewater) and pending demand (for irrigation), would be exploited down the track.

3. 1970s: TESTING THE WATERS

It would be fair to say that before the 1970s wastewater was aptly named: it was waste that happened to be water. Now the Victorian government was seeing it in a new light, not as a problem to be disposed of but as a resource. For the first time, it was to receive legislative representation as a water source. Emerging from the short 1972-73 drought was the Standing Committee on Water Supply for Victoria (established in 1973), which included a subcommittee on wastewater reuse (Stevens, 2006). Subsequent to an overseas study tour to investigate wastewater irrigation practices, the Committee recommended the drafting of wastewater reuse legislation (Lang et al., 1977), and this came to fruition in less than five years through the *Health (Amended) Act 1977* and Regulations under the Act: *Health (Use of Waste Water) Regulations 1978*. Containing microbiological standards, the Regulations were in effect the State's first guidelines for wastewater reuse (Peverill and Premier, 2006). Up until this point wastewater had not been considered in any Regulations as a potential resource.

Complementing these important legislative developments, in 1977 the Government embarked on a major research programme on the viability and safety of wastewater irrigation for vegetable production (Stevens, 2006). The research was conducted at the Frankston Vegetable Research Station, situated near the ETP, and involved irrigating vegetable crops with treated wastewater. The research was divided into two main streams, one dealing with agronomy (Kaddous and Stubbs, 1983) and the other with human health risks (Smith, 1982). In the agronomic study, five different irrigation/fertiliser treatments were applied to cabbage, carrot, celery, lettuce, spinach and tomato crops. Four of the treatments involved the use of wastewater, and one, bore water. The general finding of the study was that there was no significant difference in the marketable yield, for any of the crops, resulting from the application of the various irrigation/fertiliser treatments. Furthermore, depending on the crop type and season, irrigation with wastewater led to mean savings of 60%, 33% and 40% of the crop requirements for nitrogen, phosphorus and potassium, respectively. The accumulation of heavy metals in the soil and plant tissues did not differ significantly between treatments; however, the concentrations of heavy metals in the wastewater used were generally very low, reflecting the almost exclusively domestic origin of the sewage.

The study of the human health risks involved investigations into the retention and accumulation of bacteria, viruses and heavy metals in crops that had been spray irrigated with treated wastewater or bore water (Smith, 1982). Parasites and organic chemicals were not included in the testing regime. The bacteriological study of cabbage, carrot, celery, and tomato crops revealed that the levels of *Escherichia coli*, while being significantly higher in the wastewater than the bore water, were not significantly different when measured on the crops. The possibility of contamination of the crops irrigated with bore water from spray drift could not be discounted though. *Salmonella typhimurium* was detected on one occasion only, in the wastewater, and was never found on the vegetables. The virological study identified significantly higher levels of viruses in the wastewater compared to the bore water, but this did not translate into significant differences in levels found in the vegetables (cabbage, carrot, celery, lettuce, tomato and spinach). But before application the wastewater was stored in a retention lagoon for varying periods, and this was considered to be an important step for reducing viral loads in the irrigation water. Concentrations of up to 1,825 infectious viral units/L were detected in wastewater prior to entering the storage pond, but concentrations never exceeded 8 infectious viral units/L in the water leaving the pond. As in the agronomy study, heavy metal concentrations were relatively low in the wastewater, and the concentrations found in plants irrigated with wastewater and bore water were not significantly different.

Both the ETP and WTP were important drivers behind wastewater irrigation developments in the 1970s. The ETP began operation in 1975 but had been identified as a potential source of irrigation water for Melbourne's eastern peri-urban fringe well before it was built (Bird and Lang, 1968). The overland flow pastures at the WTP had been used successfully for livestock grazing since the turn of the century, and this raised the question of why not extend wastewater irrigation to other agricultural activities and beyond the borders of a treatment plant (Croxford, 1978; Peverill and Premier, 2006)?

4. 1980s: WHETTING THE PUBLIC'S WATER AWARENESS

Seizing the momentum of the middle and late 1970s, and backed by the positive results the Frankston study was yielding (Kaddous and Stubbs, 1983; Smith, 1982), irrigators were permitted to purchase treated wastewater for farms, market gardens, vineyards, golf courses and sports grounds (Melbourne Water, 2011d), with the first official use happening in 1981 (Peverill and Premier, 2006). Irrigation of vegetables was restricted to crops that were to be peeled, cooked or commercially processed in a manner that effectively removed the pathogen load. This initial reuse scheme was limited to irrigators within close proximity to the outfall pipe; overall, there was very little development of wastewater irrigation in Melbourne in the 1980s.

It could be argued that the decade introduced water conservation to the public consciousness and prepared Melburnians for the major challenges to come over the next two decades, including the idea of reusing wastewater. This was a paradigm shift: potable water supplies could no longer be assumed inexhaustible. Undoubtedly, the 1982–83 drought was the driving force behind this new conservation ethic in an otherwise profligate decade. Known as the 'short but sharp' drought, this was the most devastating drought of the 20th century in terms of short-term rainfall deficits (Bureau of Meteorology, 2011b). Severe water restrictions were introduced in Melbourne in February 1983 (Melbourne Water, 2002a) as a practical measure for addressing dwindling supplies in the reservoirs servicing the city, and these were augmented by other conservation measures, such as making dual flushing systems compulsory in all new toilet installations as of 1984 (Melbourne Water, 2011a).

The stakes were raised with this drought and something more was required. Perhaps buoyed by the recent success of large public awareness campaigns, such as those promoting health ('Life. Be in It'), protection against skin cancer ('Slip-Slop-Slap'), and safe driving, the Victorian Government launched the 'Don't be a Wally with Water' promotion at the height of the drought in 1983. This was the first time that a government, State or Federal, in Australia had put serious effort into public education as a means of addressing urban water security. While difficult to quantify, the campaign and other public relations efforts would generally be regarded as successful, and a broader view would not assess these solely in terms of what they achieved with regard to water conservation in the 1980s but how they added water management as another dimension to society's concerns, alongside football and cricket. Interestingly though, the conversation revolved almost exclusively around how much water we used and how much was in the reservoirs, rather than where else might we get water from. Treated municipal sewage was not yet on the public's radar. It was certainly not the chief topic of conversation at family meals and workplaces. Even greywater reuse at the household level was uncommon. All this was to come.

The importance of the 1980s in preparing Melburnians for a future that was to include wastewater cannot be understated. Because such things are difficult to measure, it is tempting to ignore or downplay their significance. But too often is water management considered in terms of mega litres and pipes. The 1982–83 drought could be regarded as a turning point in Melbourne's relationship with nature. It came carrying not just water restrictions and water awareness campaigns, but also the largest dust storm Melbourne has ever seen and, eight days later, the most devastating and deadliest bush fire, Ash Wednesday, ever to ravage the State to that point in time. Such things left an indelible imprint on the minds of Melbourne's residents. Most Melburnians could tell you what they were doing when the massive wall of dust engulfed Melbourne at 3 pm on 8 February in 1983 (AJH was in music class) and could recall digging trenches in the canopy drip-line of trees to aid effective watering of the root zone, and strategically placing inverted, water-filled fruit juice bottles throughout the garden equipped with slow-release spikes. Such activities and events were a far cry from running under the sprinkler and hosing leaves off the drive-way in the 1970s, and surely played an important role in encouraging a broader understanding of water conservation issues, which would be critical to community acceptance of more drastic and long-term water measures in the future.

5. 1990s: THE BAY: A DRIVER FOR CHANGE IN MELBOURNE'S WASTEWATER MANAGEMENT

Melbourne is situated on the northern-most shore of Port Phillip Bay, a large bay (1,930 km^2) connected to the ocean, Bass Strait, by a narrow (3.5 km) passage (Figure 1). In the 1970s the potential impact of effluent discharges from the WTP on the ecology of the Port Phillip Bay ecosystem started to receive attention. In the late 1970s and early 1980s the Melbourne Metropolitan Board of Works (now Melbourne Water) commissioned a series of studies (Environmental Services Series) on the possible effects of the WTP discharge on various biological, chemical and physical parameters in the bay. These studies were reviewed by Newell (1990) and his general finding was that the impact of nitrogen inputs on Port Phillip Bay, mainly with respect to eutrophication potential, was relatively small. He believed that the 'extremely dynamic mixing regime in the Bay accompanied by an effective exchange with Bass Strait' was one of the most important reasons for this and concluded that detrimental impacts mostly occurred in the immediate vicinity of the WTP outfall. A study by Dorsey (1982), which was not reviewed by Newell (1990), also demonstrated local impacts. He found that the intertidal infaunal communities in the immediate vicinity of the outfalls were of low species diversity and high abundance, which is typical of polluted systems.

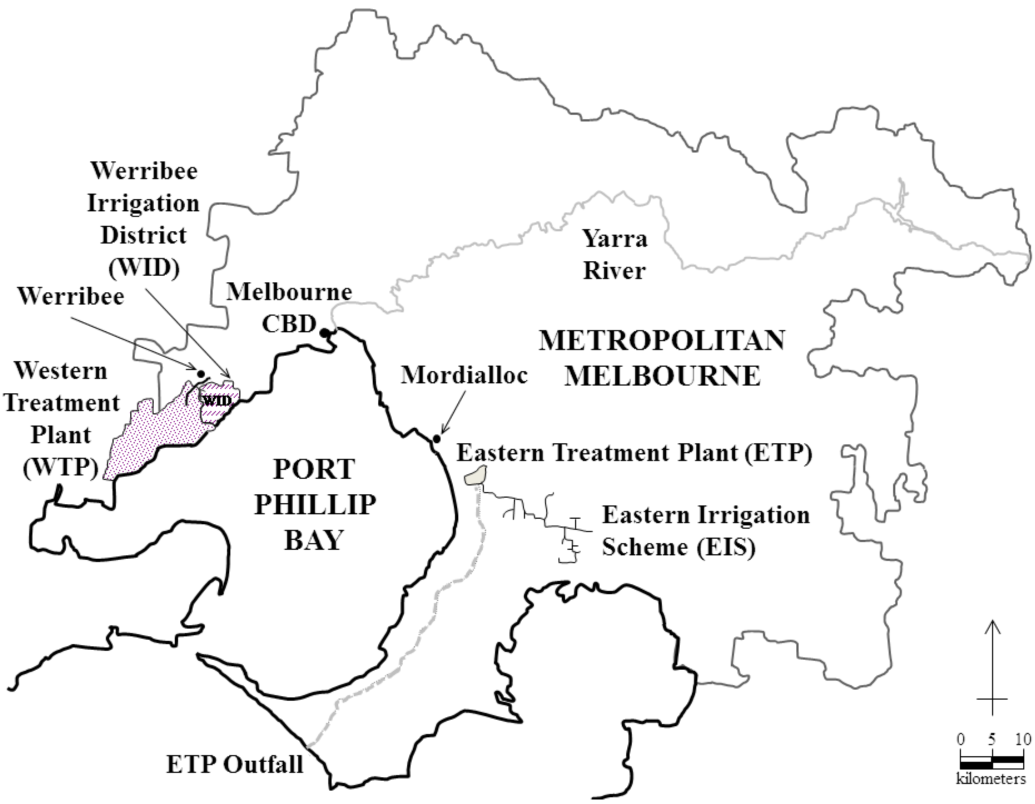

Figure 1 Map of Melbourne showing location of both wastewater treatment plants and associated irrigation schemes

The Victorian Government commissioned the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to conduct the Port Phillip Bay Environmental Study (PPBES) from 1992–1996 to assess the health of The Bay and potential threats to it (Harris et al., 1996). The PPBES was the first study to investigate the role of sediments in the nitrogen budget of Port Phillip Bay, and this proved to be critical. It overturned the previous dogma that nitrogen was exported to Bass Strait by finding that 'the nitrogen that is put into the Bay stays there in the Bay and is assimilated there'(Harris et al., 1996). While the study concluded that eutrophication of Port Phillip Bay due to nutrient (especially nitrogen) inputs from the WTP was not immediately likely, it recommended a precautionary reduction of 1,000 tonnes/y of nitrogen discharge to Port Philip Bay. Given that the WTP accounted for about half of the nitrogen entering the Bay, it was recommended that half of the reduction should come from there. Accordingly, the Victorian Environment Protection Authority amended the waste discharge licence for the WTP to achieve a reduction of 500 tonnes/y of nitrogen. From 1993 to 1998 the WTP discharged an average of 3,600 tonnes/y of nitrogen to the Bay, and therefore the revised target, to be met by 1 January 2005, was 3,100 tonnes/y, or less. Melbourne Water, the managers of the WTP, achieved the licence requirements primarily through the installation of two activated sludge plants (Melbourne Water, 2011e). Melbourne Water was also committed to decreasing the volume of effluent discharged to the Bay, and this is where a large water recycling scheme had something to offer.

6. 2000s–PRESENT: DROUGHT: WASTEWATER TO THE RESCUE?

Drought, a predominant feature of this decade, focussed the attention of politicians and the public alike on the nation's limited water resources. In 2002, a Senate inquiry into Australia's management of urban water recommended the establishment of a National Water Policy, which was to include State targets for effluent reuse and per capita water consumption reductions (Allison, 2002), and in 2003, the Council of Australian Governments (CoAG) agreed to establish a National Water Initiative (formalised in 2004; Council of Australian Governments, 2004) to encourage water conservation in cities, including expanded use of wastewater.

The State Government was also busy, releasing a White Paper: 'Securing Our Water Future Together' in 2004 (DSE, 2004) outlining the State's plans for sustainable water management. Infrastructure development was a key component of the strategy and several large-scale projects were commissioned as part of this. The Sugarloaf pipeline, a 70-km pipeline built to augment Melbourne's water supply with water saved through increased irrigation efficiencies (Sugarloaf Pipeline Alliance, 2009), was connected in 2010. In 2009, construction of Australia's largest desalination plant commenced to the east of Melbourne; this will eventually supply 150 billion L of water per year, equal to one third of Melbourne's household and industry water use combined (ABC News, 2009; DSE, 2011b). Both the Sugarloaf Pipeline and the desalination plant have been highly controversial projects, with the former being labelled as water theft from the agricultural sector (Chandler, 2008) and reigniting old country-versus-city rivalries, and the latter being seen by many as an energy-hungry and expensive solution taken as the easy way out (Hepworth, 2011). Consequently, both projects led to the establishment of large campaigns: 'Plug the Pipe' and 'Watershed Victoria', respectively (Plug The Pipe, 2010; Watershed Victoria, 2009).

Controversies aside, the Sugarloaf Pipeline and the desalination plant represent major initiatives to secure water for Melbourne. These were also complemented by water conservation programmes for homes and industry (DSE, 2004, 2007). The other string to the Government's bow was wastewater recycling. In 2002, the Victorian Government set a target to recycle 20% of Melbourne's wastewater inflows by 2010. This target was met two years early, hastened by the establishment of two major wastewater irrigation schemes. In mid-2003, vegetable growers to the west of Melbourne, who historically used abundant river and groundwater for vegetable production, were faced with a mere 5% allocation of their annual river water entitlements. With only one option at their disposal, there was such a frenzy of groundwater extraction that after only a few months a ban on groundwater pumping was imposed to protect the aquifer from sea-water intrusion (Rodda and Kent, 2008).

This was followed with the development of a Government rescue package, including the establishment of a wastewater supply from the adjacent WTP. One year later, in early 2005, the first supply of treated wastewater from the Werribee Irrigation District (WID) Recycled Water Scheme was delivered to growers (Rodda and Kent, 2008). This scheme was Melbourne's first large commercial wastewater project, providing up to 61 ML day^{-1} of tertiary treated water (ultraviolet disinfection and chlorination) to >170 customers (Melbourne Water, 2009b), primarily for commercial vegetable production (mainly broccoli, lettuce, cauliflower and cabbage). Intended as a supplementary water supply, wastewater became a critical resource as the drought dragged on. As each season passed with the hopes of 'good rainfall' unfulfilled, wastewater became the primary source of irrigation water for the majority of WID growers.

The use of wastewater in the WID has not been without challenges. As the first major wastewater reuse scheme in Victoria, initial perceptions of treated wastewater were unfavourable (with newspaper headlines such as 'This is recycled water from the city's sewage. It's going on your vegetables') (Noble, 2005). Many growers were wary of using wastewater, owing to concerns about safety and potential market impacts. Water quality was also a concern, particularly elevated salt loads, which can be attributed to industrial (44%) and domestic (25%) inputs (DSE et al., 2005). High salinity irrigation water is problematic, not only for the impact on crop yields, but also the potential long-term damage to soil. The initial 'salt reduction strategy' included three options: initially, as an interim measure, wastewater would be diluted with river water to achieve tolerable salt concentrations (~1,000 μScm^{-1} (Melbourne Water and SRW, 2004)); at-source initiatives, such as cleaner industry production processes, would be implemented to reduce discharges of salt to the sewer; and eventually, on-site treatment (desalination) at the WTP would be used to deliver any further salinity reductions required to meet salinity targets (DSE et al., 2005). Unfortunately, there have been challenges with each of these options. Drought conditions have been sufficiently severe that river water quality and quantity were insufficient to meet the dilution option for much of the time between 2006 and 2010 (SRW, 2011a), and this will continue to be a challenge in future dry years. Significant efforts were made to implement cleaner production processes, but despite these improvements, salinity levels actually increased in sewage inflows. Previously, domestic sewage inflows provided a dilution effect for higher salt inflows, but with increasingly severe water restrictions, sewage inflows declined by ~12%, resulting in higher concentrations of salt in sewage (Melbourne Water, 2008). During 2007, after conducting a range of studies, Melbourne Water concluded that the cost of a desalination plant was well beyond the commercial capacity of WID growers and therefore the decision was made not to proceed with this option (Rodda and Kent, 2008; SRW, 2011a). While a number of strategies have recently been proposed (SRW, 2011a), elevated salt loads continue to plague the scheme and remain an unresolved problem (Melbourne Water, 2008; Rodda and Kent, 2008; SRW, 2011a). Other, more acute, problems have resulted in significant lettuce crop failures. In 2006 and 2008, a number of WID growers reported stunting of lettuce crops. The wastewater was suspected on both occasions but investigations were inconclusive (Rodda and Kent, 2008). So while wastewater has been the salvation of growers to the west, it has also brought with it many difficulties that so far do not appear to be afflicting its sister scheme to the east.

The Eastern Irrigation Scheme (EIS) was also commissioned in 2005, and supplies 35 ML day^{-1} of tertiary treated water to ~80 customers (TopAq, 2010), predominantly for vegetable irrigation (especially lettuce, celery, leeks, spring onions, bok choy, and carrots), although the water is also used for garden watering and toilet flushing in two new residential developments, irrigation of golf courses, playing fields, racetracks and parklands, and in heavy industry (Hopkins, 2007; TopAq, 2008). Inflows to the ETP are primarily of domestic origin and as such do not carry the high salt loads experienced at the WTP (ETP ~ 800–1,000 μScm^{-1}, WTP ~ 1,800–>2,000 μScm^{-1} (Barker-Reid et al., 2010a, 2010b; SRW, 2011b; URS, 2009)).

Drought conditions that affected peri-urban vegetable growers also had a significant impact on households. In 2002, domestic water restrictions limiting outdoor use were implemented in Melbourne for the first time in nearly 20 years (Melbourne Water, 2002b), with water storages at just over 50%. The severity of water restrictions was increased in 2003, and in 2005 Permanent Water Saving Rules were established (DSE, 2011a). The drought continued to worsen and by the end of 2006 water storages had dropped to 38.9%—one third of the historical average. At the start of 2007, the next stage of water restrictions was implemented and within three months the situation was sufficiently dire (with water storages at 29.3% capacity) that a new, higher level of water restrictions was created (Melbourne Water, 2011a) in an attempt to curb domestic water use while minimising economic (and political) fallout. In 2008, the 'Target 155' campaign was launched to encourage individuals to use a maximum of 155 L of tap water per day, with water companies adding illustrations to water bills comparing household water use with the target (Melbourne Water, 2011a). The devastation of the Ash Wednesday fires of 1982 was firmly embedded in the psyche of the nation, but it was surpassed by the horror of the 'Black Saturday' fires in early 2009. The fires claimed the lives of 173 people (Parliament of Victoria, 2010) and damaged ~30% of Melbourne's water supply catchments (Melbourne Water, 2009a), and by mid-2009, water storages had reached their lowest level since dam construction in 1984 (25.5%) (Melbourne Water, 2011a).

While water restrictions have been applied in Melbourne on numerous occasions since 1939 – following the WWII drought of 1937/38, the summer of 1945/46 and a severe drought in 1967/68 – the 'noughties' marked the start of a new era of water conservation. While studies conducted in the 1980s and 1990s consistently reflected the importance placed on water conservation (Dolnicar and Hurlimann, 2010), events in recent years may have contributed to a change in water conservation attitudes and behaviours (Dolnicar and Hurlimann, 2010; Head and Muir, 2007). Media influences in relation to water consumption and the drought were diverse and pervasive during the 2000s. From campaigns to promote domestic potable water conservation (Clarke and Brown, 2006) through to daily reporting of dam levels on the TV news (Head and Muir, 2007), people were bombarded with information.

Initially there was significant resistance to water restrictions, but over time Melburnians have adapted to sustained drought conditions. Water restrictions have become a part of everyday life, with 90% of households in 2005 reporting water conservation behaviours such as the use of water saving devices (such as efficient shower heads) and/or practices such as taking shorter showers (ABS, 2005). Victorian household water use practices have changed dramatically, with per capita water use reduced by 16% between 2000–2001 and 2004–2005 (ABS, 2006) and a further 22% by 2009 (ABS, 2010c).

The Millennium Drought also brought about a shift in local government and planning regulations. Once illegal in many cities, rainwater tanks are now a proud feature of urban and rural properties in response to government incentives in the form of rebates for tank installations. The use of water from rainwater tanks in Victorian households has increased from 13.9% in 1998, 16% in 2004, 16.7% in 2007, to 29.6% in 2010 (ABS, 2010a). A similar increase has been reported in urban areas, with 25.5% and 22.7% of Melbourne households using rainwater in 2009 and 2010, respectively (ABS, 2010a, 2010b).

It has been argued that it is the role of the backyard garden in daily life that has facilitated this greater connection to the water networks that underpin urban life in Australia. 'It is in the relationship between house and garden that people see, understand and participate in the network of water storage and distribution…..people love their gardens and are willing to work hard to save them' (Head and Muir, 2007). Water restrictions specifically target outdoor water use, but many Melburnians did not want to give up their garden. Instead, they became creative and found ways to conserve and reuse water from around the house – from the bucket in the shower to the washing machine hose discharging onto the lawn – activities referred to as 'water gathering' (Head and Muir, 2007). Households had now found 'new' water that would help keep their gardens alive.

This was a significant shift in attitudes. The work of researchers around the world has shown that acceptability of water reuse is highest for low personal contact activities, i.e., it decreases with increasing personal contact (Clarke and Brown, 2006; Hurlimann and Dolnicar, 2010; Hurlimann et al., 2007), but it appears that in some situations Australians are willing to tolerate at least some level of contact. Recent surveys have reported high levels of acceptance for irrigation of vegetables with wastewater (Hurlimann and Dolnicar, 2010; Marks et al., 2006) and many households are reporting reuse of greywater (Clarke and Brown, 2006; Dolnicar and Hurlimann, 2010; Head and Muir, 2007). These changes have occurred rapidly. In just a few years, people's attitude to greywater shifted to such an extent that 70% of Melburnians reported using greywater in 2007 (ABS, 2007). It is now widely perceived as harmless and its use is generally as untreated greywater either immediately after generation, or after some period of storage （While there is a sense of limited or low risk associated with greywater reuse amongst the public, this view is not shared by government authorities. The EPA produced a factsheet on domestic greywater reuse expressing a more cautious view. Similar to guidelines and from other countries, this document discourages various practices such as greywater irrigation of vegetables to be consumed raw and storage of greywater for more than 24 hours (EPAV, 2008).）.

But then it rained! By late 2009 inflows into storage dams had increased with levels reaching 38%. Water restrictions were eased in April (to 2007 levels) and again in September 2010—back to restriction levels last experienced in 2003—with the wettest spring since 1992 and water storage levels at 40% (Austin, 2010; Melbourne Water, 2011a).

Interestingly, it appears that the relaxing of water restrictions may have had an impact on household water use behaviours. Household reuse of greywater has been included in national surveys since 1998. For Victorian households with a garden, the proportion using greywater steadily increased from 12% in 1998 (ABS, 2004) to 46% in 2007, while incredibly, 71% of Melbourne households reported using greywater in 2007 (ABS, 2007). The most recent survey (2010) has reported a shift, with only 42% of Melbourne households, and 26% of Victorian households with a garden, using greywater (ABS, 2010a).

Treated sewage for agriculture and amenity horticulture, on-site greywater reuse at the household level—the next step was obvious: treated sewage for residential estates. In March 2009, residents at the new Aurora residential estate became the first in Melbourne to receive treated sewage via a 'third-pipe' scheme (Apostolidis et al., 2011; Madden, 2009). In addition to the provision of potable water and waterborne sewerage (i.e., two pipes), a household connected to such a scheme also receives treated wastewater (from the third pipe) for non-potable uses. This treated wastewater is not obtained from the individual household, but rather from a wastewater treatment plant servicing a community. These systems are also known as dual-reticulation, because instead of the conventional single reticulated water supply (potable water) there are two supplies where the second is a 'purple-pipe' used to make the pipes carrying the treated wastewater readily recognisable (Parker, 2008; Purple Pipe Association Inc., 2011). Aurora is located on the northern fringe of Melbourne, 25 km from the city's centre, and is part of Melbourne's north-eastern corridor of development. It is an exemplar for sustainable residential development and once fully occupied, it is expected that the estate will house 25,000 residents. The Aurora development has its own wastewater treatment plant plus a recycled water treatment plant comprising microstrainers, ultrafiltration membranes, ultra-violet disinfection, and chlorination (Yarra Valley Water, 2011). Uses of the third-pipe water at the estate include toilet flushing, household garden watering, car washing, and irrigation of public amenities (Yarra Valley Water, 2011). There are now numerous other third-pipe schemes across Melbourne and there are plans for many more. In the north-eastern corridor alone, 50,000 residences are expected to be serviced with third-pipes within the next 25 years (Madden, 2009). In the west, the same treated wastewater from the WTP that is being distributed to vegetable growers is now being delivered to a school (MacKillop College, Werribee) and a 925-ha employment precinct (Werribee Employment Precinct) via third-pipe systems (City West Water Limited, 2011). Planned/under construction housing developments in the west, including Manor Lakes, Bluestone and Riverwalk, will also have third-pipe connections carrying the WTP water (Arris Pty Ltd, 2011). There is even more activity in the east, with the same water that is supporting the market gardens being used for third-pipe systems. By 2012, there will be 28 residential and one industrial third-pipe estates in suburbs close to the ETP (South East Water, 2011b).

The past decade has also seen the quiet rise of stormwater harvesting and use. Stormwater, defined as the runoff from pervious and impervious surfaces in predominantly urban environments, is a water resource that Melbourne is only now starting to capitalise on. Australia's urban water authorities have, over time, managed water supply, stormwater drainage and wastewater disposal separately. This approach dates back to the aforementioned sanitation problems of 19th century Melbourne that prompted the development of piped water supply systems and sewers. Some years later, to alleviate the load on the sewerage system, authorities constructed a separate stormwater drainage network.

In 1999 it was estimated that the average annual volume of urban stormwater runoff in Melbourne was almost equal to the average annual urban water usage (Mitchell et al., 1999). At the time, the majority of stormwater re-use consisted of roof rainwater harvesting for residential gardens (Coombes et al., 2002), or stormwater runoff harvesting for groundwater recharging (Dillon et al., 1999). The case was also being made for the introduction of stormwater re-use schemes to provide additional water for Australian cities (Coombes et al., 2002; Mitchell et al., 1999; Newton et al., 2001; Thomas et al., 1997). In general though, stormwater was considered 'neglected', due largely to the lack of infrastructure for its treatment (Thomas et al., 1997).

Today the situation is very different. The drought, together with concepts like Water Sensitive Urban Design, has prompted the development of many stormwater harvesting initiatives across Melbourne. For example, South East Water (Authority) is constructing a stormwater treatment facility that will provide third-pipe water to a new housing estate (Avenview in Melbourne's Eastern Growth Corridor). The facility will begin supplying treated stormwater in late 2011 (South East Water, 2011a). Similarly, Melbourne City Council has begun construction of a stormwater harvesting and treatment facility in on the eastern edge of the city's CBD that it hopes will save 21 ML of potable water each year. The treated stormwater will be used to irrigate street trees and city parks. Dozens of similar initiatives have been established across Melbourne (Melbourne Water, 2011c), where the predominant end-use for stormwater is now irrigation of public open spaces and golf courses (Philp et al., 2008).

CONCLUSIONS

Melbourne is currently one of the most active cities with respect to wastewater irrigation. Not only does it host two large peri-urban irrigation schemes associated with the city's two major wastewater treatment plants, but reclamation of greywater at the household level is common.

Wastewater irrigation in Melbourne is not without its problems though. Salinity issues threaten the long-term sustainability of wastewater irrigation in the WID while the reuse of greywater in backyards requires further attention. The difficulty in regulating backyard irrigation practices places a question mark over the safety of greywater irrigation and further research is urgently required to quantify the disease burden associated with household greywater irrigation.

Melburnians have demonstrated their willingness to accept severe water restrictions and new water conservation behaviours. While recent rainfall has taken water conservation issues out of the headlines, it will be interesting to see what challenges arise from the next drought and the broader impacts of climate change.

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