



Potable Water Reuse What can Australia learn from global experience?

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Stuart Khan and Amos Branch

UNSW Water Research Centre, University of New South Wales, NSW, Australia.

WaterRA Project #3039

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Location:

WaterRA Head Office
Level 2, 250 Victoria Square, Adelaide SA 5000

Postal Address:

GPO BOX 1751, Adelaide SA 5001

For more information about WaterRA visit the website www.waterra.com.au

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Final Report Project #3039

ISBN 978-1-921732-50-8

Foreword by Water Research Australia

This project was initiated by WaterRA to provide our member organisations with an update on the current status and trends relating to the implementation of potable water reuse schemes around the world, at a time when options for future drinking water supplies are being considered in many parts of Australia. It was intended to build upon previous Australian reports, which have focused on various aspects of water recycling including for indirect and direct potable reuse (Radcliffe, 2004; ATSE 2013).

The project was prompted by WaterRA's observation that in a number of international locations there has been rapid progress in the development of new potable reuse projects, as well as evolution of the governance and regulatory structures required to support them. In order to ensure that Australian water managers and decision makers are well informed of these developments, this work was proposed to provide a timely and technically robust update.

The scope for this report was to provide a summary of key developments and the current status of potable reuse practice, with the goal of identifying and understanding the drivers and incentives that have underpinned progress. In particular the report was to include an overview of recently produced guidelines and best practice documents, with a particular focus on the ways in which international and Australian regulators have approached regulation of potable reuse for the prime purpose of ensuring full protection of public health. As a consequence of this focus, aspects such as the economics and energy requirements of potable reuse are not addressed herein.

In the context of global experience, the scope of this report included an assessment of the readiness of the Australian water industry and regulatory frameworks for the possible future expansion of potable reuse. Community perspectives on potable reuse were also to be considered, particularly in terms of lessons and insights that may be relevant in an Australian context. Finally, pathways to support successful potable reuse in Australia were to be discussed and relevant specific recommendations to be drawn from this discussion.

WaterRA considers that this report, which has been independently peer-reviewed, effectively addresses the above objectives and can be used with confidence as an input to discussions and decisions regarding potable reuse in the Australian context.

Executive Summary

With over 50 years of practical experience, planned potable reuse has become an important water supply management strategy for a growing number of towns and cities around the world. The World Health Organization (WHO) has recognised that “*potable reuse represents a realistic, practical and relatively climate independent source of drinking water*”. However, the WHO went on to say that “*potable reuse schemes will be complex and proponents will need to have sufficient resources and capabilities for successful implementation*”.

For this reason, it is necessary for any jurisdiction contemplating the development of a potable reuse project to equip themselves with a robust understanding of global experiences, use these to inform an appropriate regulatory approach, and apply this to the current status of ‘best practice’ for project design and management.

The purpose of this report is to provide a current update of the global status of planned potable reuse as a water supply strategy. Though important, economic and energy issues have been excluded from this review. It is intended that this may be of value to Australian decision makers and their advisors, as they consider appropriate policies for future drinking water supply augmentation and management.

The US State of California has been an international leader on a journey involving the development of potable reuse since the 1960s. Following the experience of Australia’s ‘millennium drought’ (peaking during 2006-2008) and a similarly timed drought in Southern California (peaking 2007-2009), some Australian states (notably Western Australia and Queensland) have joined this journey. Since then, Australian water supply managers, planners, and researchers have taken considerable interest in developments around potable reuse in California and the USA more generally. This has included various forms of collaboration, including information sharing, collaborative funding and participation in research projects, and the development of professional networks through peak industry and research bodies in both countries.

Global status of planned potable reuse projects

An important approach to planned potable reuse has been by the use of recycled water to replenish groundwater systems. This practice is referred to as groundwater replenishment and has been successfully practiced for more than 50 years.

The Montebello Forebay Groundwater Replenishment Project was a pioneering project, established in Los Angeles County, California in 1962. Another important Californian project was known as Water Factory 21 and operated in Orange County from 1976. Due to a need to expand capacity, Water Factory 21 was decommissioned in 2004 and replaced in 2008 by what is now the world’s largest

planned potable reuse project, the Groundwater Replenishment System (GWRS). The GWRS currently has capacity to produce up to 350 megalitres (ML) of recycled water per day and work is soon to begin (in 2019) on expanding this capacity to 500 ML per day by 2023.

Inspired by successes in California, other cities have adopted similar groundwater replenishment projects, including Wulpen in Belgium and Perth in Western Australia. The Groundwater Replenishment Scheme (also known by the abbreviation GWRS) in Perth has been operating at full-scale since 2017, with capacity to recharge the Leederville and Yarragadee aquifers with up to 40 ML per day. This scheme is now undergoing expansion with capacity expected to double (to 80 ML per day) during 2019. It is proposed that by 2060, groundwater replenishment could recycle 315 ML per day or 115 gegalitres (GL) per year into aquifers near Perth.

An alternative approach to planned potable reuse is the use of recycled water to recharge surface water systems, such as rivers, lakes or dams. This practice, known as surface water augmentation has been practiced for over 40 years. An important surface water augmentation project was developed by the Upper Occoquan Service Authority in Virginia, USA and began operation in 1978. The facility currently has the capacity to produce 200 ML per day of recycled water, which is used to supplement other supplies in the Occoquan Reservoir. This reservoir is a critical component of the water supply for approximately 1.5 million residents of northern Virginia. Surface water augmentation projects have since been developed in Singapore (since 2003) and others are under development in San Diego, California.

The Western Corridor Recycled Water Scheme (WCRWS) was developed in South East Queensland with the capacity to produce up to 230 ML per day of recycled water. The WCRWS is currently in care and maintenance mode but when needed, recycled water could be used to augment supplies in the region’s largest surface water reservoir, Lake Wivenhoe. Based on the current water security planning protocols, the WCRWS will start remobilisation in the event that combined South East Queensland bulk water storages reduce in volume to below 60% of their full capacity.

Some cities have developed planned potable reuse projects that include neither a groundwater replenishment process, nor the augmentation of a significant surface water supply. This practice, known as direct potable reuse (DPR) has been successfully implemented in the city of Windhoek, Namibia for over 50 years (since 1968).

More recently (since 2013), DPR has been practiced in Texas, USA with projects developed in the cities of Big Spring and Wichita Falls. Further projects are currently being developed, including one

for the City of El Paso. A number of Californian cities, including San Diego and Ventura, are closely observing developments in regulatory criteria to facilitate future DPR in that State and have indicated an interest in future application.

Drivers and incentives for potable reuse

For the vast majority of planned potable reuse projects, the key overriding driver has been the need to expand water supply capacity to meet growing demand. In some cases, this has been exacerbated by long-term changes in conventional water supply availability. In others, the need for supply expansion has been brought about by intense immediate drought conditions. In a few cases, water quality considerations have underpinned decisions to enhance water treatment and risk management by the establishment of a formally recognised potable reuse project. This has occurred in situations where treated sewage is discharged upstream, or in the proximity of, a drinking water intake. Such situations are increasingly recognised and referred to as *de facto* potable reuse. Another driver has been the opportunity to avoid major wastewater infrastructure augmentation costs. Each of these drivers may be expected to continue to underscore the development of potable reuse projects in Australia and internationally.

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. This is a highly geographically specific consideration and thus very different conclusions are 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 supply option, based on considerations of criteria including water supply availability, cost and energy consumption.

Guidelines and best practice

There are now a number of well-developed frameworks for managing risks from drinking water and recycled water. These include frameworks developed in Australia, the USA and by the World Health Organization (WHO).

Australian water quality guidelines developed since 2004 have exhibited a significant philosophical departure from the traditional focus on 'end point monitoring' as a means of water quality compliance. Instead, they have adopted a 'risk management' approach, also embodied in the WHO Guidelines for Drinking Water Quality and the Water Safety Plans described therein. This approach emphasises the assessment and management of possible means by which contaminants may be introduced to water, and preventative measures for eliminating contamination. With reduced

emphasis on end-point monitoring, Australian regulations have focussed on implementation of risk management plans.

Australian Guidelines for Water Recycling (AGWR) were developed in two phases. The AGWR (Phase 1) established a risk-management based framework for non-potable water recycling in 2006 and AGWR (Phase 2) built upon this framework for various specific applications, including the augmentation of drinking water supplies in 2008. Recent WHO Guidelines for Potable Reuse (2017) have closely followed many of the approaches established by the AGWR.

Australian and WHO water recycling guidelines have adapted and built-upon successful drinking water risk management frameworks. Water recycling guidelines have further progressed a number of additional concepts, such as the application of health-based targets for water quality, which are now being actively considered for adoption in future revisions of the Australian Drinking Water Guidelines. Some key aspects of process validation and monitoring have also been further developed for water recycling, and may be reflected in future drinking water guidance.

Regulatory agency approach to potable reuse

The Guideline documents discussed above outline broadly agreed approaches for the safe design, operation and management of potable water reuse projects. The AGWR represent generally agreed principles, by all Australian jurisdictions, via the Ministerial Councils under whose endorsement they have been published. State-based regulatory agencies have played key roles in formulating appropriate water quality and safety objectives. Given this involvement in their development, the AGWR provide a reliable indication of the general philosophy that will underpin the assessment of future potable reuse projects in Australia.

However, the Guideline documents are not themselves legislated regulations. Thus it remains the responsibility of drinking water regulators to develop and impose criteria and other requirements to ensure the safe operation of potable reuse projects.

It is apparent that satisfactory regulatory frameworks for planned potable reuse are currently in place in some Australian states including Queensland and Western Australia. Since planned potable reuse (as opposed to *de facto* potable reuse) is not currently practiced in the other states, it is understandable that appropriate policy and regulatory frameworks have not been fully developed. Nonetheless, no explicit legislative barriers to potable reuse exist and there is some evidence that existing drinking water and recycled water legislation could be applied

together as they exist, in lieu of creating new overarching laws. An example of such compatible existing legislation is the *Safe Drinking Water Act, 2011 (SA)*, which could be applied to potable reuse without modification.

Readiness of the Australian water industry and regulatory frameworks

The success of the GWRS in Western Australia is sufficient evidence that potable reuse projects can be successfully planned and implemented in Australia. Although currently not operating, the successful construction and validation of the WCRWS in South East Queensland provides an indication that the opportunities for such successes are not limited to the west coast of Australia.

To assess the readiness of the Australian water industry and its regulatory frameworks for the wider implementation of potable reuse, two important factors are briefly considered in this chapter. These are the current attention to urban water planning in Australia and the role of politics in potable reuse.

Urban water management in Australia is well advanced in many important areas. However, the industry has witnessed an observable reduction in priority and profile of urban water planning since the end of the millennium drought. Intergovernmental and statutory institutional structures, such as the National Water Commission have been abolished. Water policy complacency is evident and reform impetus is at risk of being lost. Support for water research has also reduced with funding for the Australian Water Recycling Centre of Excellence not having been extended. However, a number of important activities continue, including those of the National Water Reform Committee, which is undertaking work to identify national water reform priorities.

By international standards, the water quality regulatory landscape in Australia is widely considered to be world-leading. Despite this, the Australian water quality regulatory landscape is constrained in terms of personnel numbers. As with many other industries, the water industry faces significant risks due to the challenges of succession planning for an ageing work force. As the more experienced senior staff approach retirement, it will be crucial that younger staff members are trained, qualified and ready to succeed them. If formalised policies and practices are not currently in place to retain the significant technical and leadership skills with the organisations, the ability to move forward with the ever-evolving landscape of water quality management will be hampered in the future.

This analysis indicates that the obstacles to (increased) potable reuse in Australia are, for the most part, not technical obstacles. That is, 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.

Community perspectives around potable reuse

Since the 1970s, numerous studies have been undertaken to characterise community attitudes to potable and non-potable water recycling in various countries, including Australia. These have generally indicated strong and widespread support for most non-potable applications, but lower levels of acceptance for potable water reuse. It is important to note that community perspectives are complex, variable and will shift with time, access to information, as well as contextual considerations such as current water availability or shortage conditions.

To fully understand community attitudes to water recycling, it is necessary to consider instinctive and emotional responses that people naturally have to human excrement and sewage. Cognitive responses may explain many of the less rational perceptions that people may have about water recycling. Such responses can create mental barriers to the acceptance of recycled water for drinking. These mental barriers have commonly been referred to as the “yuck factor”.

Despite the inherent barriers to widespread community acceptance of potable reuse, the successful projects described in this report (see Appendix I), confirm that the barriers are not insurmountable. The WHO has stated 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. They state that a sustained and comprehensive public communication plan that addresses the health, safety and quality concerns throughout the various stages, from planning to implementation, is an essential tool to advance the success of projects.

Some key factors demonstrated to be effective for better informing community stakeholders include the need to increase availability of important information to community members, and ensuring a clear understanding of the need for potable reuse. Timing and language used in potable reuse communications are also very important considerations with implications for community acceptance.

Visitor centres have been a valuable and effective aspect of some successful potable water reuse projects. A well-planned visitor centre can offer a wide range of opportunities for community engagement and education. Important established examples include visitor centres and demonstration plants that have been developed in Singapore, Perth and San Diego.

A collection of available education products, that were collated during a research project between 2011 – 2014, have been developed and are now available for access by Australian water utilities wishing to develop public engagement materials. The

available materials can be adapted to incorporate local content and context, be combined in various ways, and linked to school curricula or existing utility educational materials and programmes. The materials are also adaptable to multiple display platforms such as kiosks, long-form documentaries, video walls, interactive screens, social media and phone and tablet applications.

Pathways to support successful potable reuse in Australia

At the conclusion of this report, some important changes are identified, which are needed to enhance the viability of potable reuse in Australia. Until such changes can be effected, long-term water planning for many Australian towns and cities will remain stymied.

A national strategy for urban water management is needed in Australia. The 2004 Intergovernmental Agreement on a National Water Initiative (NWI) was the most recent document that can be considered to provide a national strategy for water management generally. The National Water Commission (NWC) was established in 2005 to oversee and progress the implementation of the objectives of the NWI. The NWC undertook a number of major projects and produced a series of important reports, aimed at progressing the viability of potable reuse projects in Australia. However, the NWC was abolished in 2014. Some of the roles of the NWC were transferred to the Productivity Commission and the Bureau of Meteorology, but no agency has taken on clear responsibility for overseeing any further progression of the NWI.

The range of potential benefits that might flow from a new national strategy for urban water management is beyond the scope of this report, but could include a consistent and coherent approach to assessing opportunities and planning for potable reuse projects. Consistent terminology, application of communication strategies, and risk management programs would all be highly advantageous for the efficient development of potable reuse opportunities. Furthermore, a national strategy would facilitate the identification of national research priorities, thus improving the targeting of research funding to address key relevant knowledge gaps.

It is proposed that a future revision of the AGWR (Phase 2) be planned, whereby this document becomes a stand-alone additional (and optional) module of the Australian Drinking Water Guidelines. Such an amalgamation would ensure consistency between the two documents. It would also facilitate ongoing revision and update to the AGWR, as currently occurs for the Drinking Water Guidelines.

An enhanced industry-wide water quality safety culture among the Australian water industry should be developed. It is proposed that the water industry should look to examples from other industries, such as aviation and oil and gas industries. These examples

suggest that a long-term adaptive process must be established to capture and learn from minor errors and deviations from standard procedures. Water utilities could register and report such deviations on a voluntary basis, or regulators could require reporting and data sharing to continually improve knowledge and safety standards.

A politically determined pre-emptive position against planned potable reuse is not ideal when considering sustainable water supply options for the community. This sentiment has been echoed in point 5 of the Australian Governments National Urban Water Planning Principles – “Consider the full portfolio of water supply and demand options”. Even in circumstances where potable reuse may not prove to be a component of an optimum water supply portfolio for a particular town or city, it remains preferable that this option is available for open and transparent comparison with other alternative water supply strategies. It is suggested that politicians should adopt a policy position of having all potential water supply options ‘on the table’ for careful, scientific and systematic assessment of the advantages and limitations of each option, in each circumstance.

Recommendations

A series of recommendations stemming from the contents of this report are summarised below. These recommendations are aimed at helping to better inform and support key aspects of future potable reuse projects in Australia. It is proposed that doing so will maximise the ability of Australian towns and cities to plan for safe, sustainable and affordable water supply systems of the future.

1. A national strategy for urban water management should be developed. Such a strategy would update and extend some aspects of the 2004 National Water Initiative as recommended by the National Water Commission and the Productivity Commission. A national strategy should be jointly agreed to by the Commonwealth with the State and Territory governments.
2. A renewed national strategy for urban water management should be effectively supported by an appropriate national body tasked with responsibility for overseeing implementation and suitably funded to meet this responsibility.
3. A strategy for increased skills and competence assurance for advanced water treatment processes should be developed, supported and managed by national water industry bodies.
4. The module of the Australian Guidelines for Water Recycling, which deals specifically with the use of recycled water for the augmentation of drinking water supplies (AGWR Phase 2), should be revised in future so that this document becomes a stand-alone additional module of the Australian Drinking Water

Guidelines (ADWG). This would facilitate internal consistency between these two documents, avoid unnecessary repetition and provide a means for ongoing rolling revision of the AGWR (Phase 2), as it currently exists for the ADWG.

5. Australian water utilities should work to develop an enhanced industry-wide water quality safety culture. This should include examining requirements for corporate board composition to include water quality and public health expertise. Furthermore, the water industry should look to examples from other industries, e.g. the aviation industry. A long-term adaptive process must be established to capture and learn from minor errors and deviations from standard procedures. Water utilities could register and report such deviations on a voluntary basis, or regulators could require reporting and data sharing to continually improve knowledge and safety standards.
6. Long-term community engagement strategies should be developed as these have been shown to significantly influence project success. This includes the need for a consistent national strategy as well as locally-focused strategies, designed to be relevant to individual towns and cities that may have a reason to consider the development of planned potable reuse in the future. This is a challenge that will need to be taken up by individual local water utilities.
7. The Australian water industry should continue to work toward providing confidence in potable reuse for governments and other decision makers. This includes confidence that the industry and its regulators can competently manage potable reuse projects.
8. Urban water planning should be conducted in line with point 5 of the Australian Governments National Urban Water Planning Principles – “Consider the full portfolio of water supply and demand options” without recourse to politically determined policy bans on recycled water.

Contents

Foreword	4
Executive Summary	5
Contents	10
Figures.....	12
Tables	13
Abbreviations	14
Glossary of Water Reuse Terminology	15
1 Introduction.....	16
2 Global Status of Planned Potable Reuse Projects	17
2.1 Planned potable reuse by groundwater replenishment since 1962.....	17
2.1.1 California, USA	17
2.1.2 Belgium.....	18
2.2 Planned potable reuse by surface water augmentation since 1978.....	18
2.2.1 Virginia, USA	18
2.2.2 Singapore.....	19
2.2.3 California, USA.....	19
2.3 Direct potable reuse in southern Africa since 1968.....	20
2.3.1 Namibia.....	20
2.3.2 South Africa.....	21
2.4 Direct potable reuse in Texas, USA since 2013.....	21
2.4.1 Big Spring.....	21
2.4.2 Wichita Falls	22
2.4.3 El Paso.....	22
2.5 Planning for direct potable reuse in California.....	22
2.6 Growing interest in non-membrane treatment trains for potable reuse	23
2.7 Planned potable reuse in Australia.....	24
2.7.1 Western Corridor Recycled Water Scheme (WCRWS), QLD, Australia.....	24
2.7.2 Groundwater Replenishment Scheme (GWRS), Perth, WA, Australia.....	26
3 Drivers and Incentives for Potable Reuse	26
3.1 Drivers for potable reuse	26
3.1.1 Need to expand water supply capacity to meet growing demand.....	26
3.1.2 Conversion of <i>de facto</i> potable reuse to planned potable reuse	27
3.1.3 An opportunity to avoid major water or wastewater infrastructure augmentation.....	28
3.2 Incentives for potable reuse.....	28
3.2.1 Design and life cycle comparison of water supply options	29
3.2.2 Triple bottom line analysis to evaluate water supply options	30
3.2.3 Context-specific nature of water supply decisions	31
4 Guidelines and Best Practice.....	32
4.1 Australia.....	32
4.1.1 Australian Drinking Water Guidelines.....	32
4.1.2 Australian Guidelines for Water Recycling – Phase 1.....	33
4.1.3 Australian Guidelines for Water Recycling – Phase 2.....	34
4.1.4 Validation of treatment processes for AGWR treatment performance.....	34
4.2 The World Health Organization	35
4.2.1 Water quality targets and microbial performance targets	35
4.2.2 Application of water safety plans to potable reuse.....	36
4.2.3 Validation of control measures.....	36
4.2.4 Bioassays for direct toxicity testing.....	38
4.3 The USA.....	38

Contents

5 Regulatory Agency Approach to Potable Reuse.....	40
5.1 United States regulatory agencies.....	40
5.1.1 California’s Title 22 Code of Regulations.....	40
5.1.2 Proposed framework for regulating direct potable reuse in California.....	41
5.1.3 Texas Commission on Environmental Quality (TCEQ).....	43
5.2 Australian regulatory agencies.....	44
5.2.1 Queensland.....	44
5.2.2 Western Australia.....	45
5.2.3 Other Australian states.....	46
6 Readiness of the Australian Water Industry and Regulatory Frameworks	48
6.1 Current attention to urban water planning.....	48
6.2 The role of politics in potable reuse.....	49
7 Community Perspectives Around Potable Reuse	51
7.1 Availability of information.....	51
7.2 An understanding of the need.....	52
7.3 Timing.....	52
7.4 Language.....	52
7.5 Knowledge of urban water cycles.....	53
7.6 Societal legitimacy versus technical capability.....	53
7.7 The role of water recycling visitor centres.....	53
7.8 Available community engagement resources: Water360.....	54
8 Pathways to Support Successful Potable Reuse in Australia.....	55
8.1 A national strategy for urban water management.....	55
8.2 AGWR (Phase 2) to merge with Australian Drinking Water Guidelines.....	55
8.3 Enhanced water quality safety culture in the Australia.....	56
8.4 Policy positions of state governments and opposition parties.....	56
9 Acknowledgements	57
10 References	58
Appendix I – Global Examples of Planned Potable Reuse	65
10.1 Montebello Forebay, California, USA.....	65
10.2 Groundwater Replenishment System, Orange County, California, USA.....	66
10.3 Upper Occoquan Service Authority, Virginia, USA.....	67
10.4 Gwinnett County, Georgia, USA.....	68
10.5 Goreangab Water Reclamation Plant, Windhoek, Namibia.....	69
10.6 Beaufort West Water Reclamation Plant, South Africa.....	70
10.7 ‘NEWater’, Singapore.....	71
10.8 The Torreele/St-André facility in Wulpen, Belgium.....	72
10.9 Western Corridor Recycled Water Scheme (WCRWS), QLD, Australia.....	73
10.10 Groundwater Replenishment Scheme (GWRS), Perth, WA, Australia.....	74
10.11 Prairie Waters Project, Aurora, Colorado, USA.....	75
10.12 Raw Water Production Facility, Big Spring, Texas.....	76
10.13 Ongoing development of new potable reuse projects in the USA.....	77
10.13.1 San Diego, California.....	77
10.13.2 Ventura, California.....	78
10.13.3 El Paso, Texas.....	78

Figures

Figure 1: The ‘multiplier effect’ showing increased water availability as a result of closing the loop with increased proportions of potable reuse.....	27
Figure 2: An example radar chart used to visualise and compare the unweighted triple bottom line results for each WSO. In this example, WSO1 (the base case), WSO2 (IPR) and WSO3 (DPR) (Stanford <i>et al</i> , 2018).....	31
Figure 3: An example of a Water360 product in the reception area of the Water Replenishment District of Southern California.....	54
Figure 4: Process flow diagram for the Montebello Forebay potable reuse project.....	65
Figure 5: Process flow diagram for the Groundwater Replenishment System, Orange County, California.....	66
Figure 6: Process flow diagram for the Upper Occoquan Service Authority potable reuse project.....	67
Figure 7: Process flow diagram for the Gwinnett County potable reuse project.....	68
Figure 8: Process flow diagram for the NGWRP.....	69
Figure 9: Process flow diagram of the Beaufort West DPR Project.....	70
Figure 10: Process flow diagram for NEWater potable reuse in Singapore.....	71
Figure 11: Process flow diagram for the Torreele/St-André facility in Wulpen, Belgium.....	72
Figure 12: Process flow diagram for the Western Corridor Recycled Water Scheme (WCRWS), Brisbane.....	73
Figure 13: Process flow diagram for the Groundwater Replenishment Scheme (GWRS), Perth.....	74
Figure 14: Process flow diagram for the Prairie Waters Project, Aurora, Colorado.....	75
Figure 15: Process flow diagram of the Big Spring DPR scheme.....	76

Tables

Table 1: Performance targets calculated from default concentrations of pathogens (WHO 2017).....	35
Table 2: Validated log reduction values based on challenge testing and operational monitoring sensitivity (LRVC-test and LRVOMS) for indicative treatment processesa (WHO 2017).....	37
Table 3: Indicator chemicals used for the Beenyup potable reuse scheme, Perth, Australia (WHO 2017).....	38
Table 4: Pathogen reduction requirements prior to surface water augmentation (California Office of Administrative Law, 2019).....	41
Table 5: State-based regulation for drinking water and recycled water and relevant departments	47

Abbreviations

ADWG	Australian Drinking Water Guidelines	MF	Microfiltration
AGWR	Australian Guidelines for Water Recycling	MFGRP	Montebello Forebay Groundwater Replenishment Project
AOP	Advanced oxidation process	ML	Megalitre (1 million litres)
ATSE	Academy of Technological Sciences and Engineering	NDMA	N-Nitrosodimethylamine
AWTP	Advanced water treatment plant	NHMRC	National Health and Medical Research Council
BAC	Biologically activated carbon	PRW	Purified recycled water
CCP	Critical control point	RO	Reverse osmosis
DALY	Disability-adjusted life year	RWPF	Raw Water Production Facility
DPR	Direct potable reuse	TBL	Triple bottom line
FAT	Full advanced treatment	TCEQ	Texas Commission on Environmental Quality
GAC	Granular activated carbon	TOC	Total organic carbon
GL	Gigalitre (1 billion litres)	TTC	Threshold of toxicological concern
GWRS (1)	Groundwater Replenishment System (potable project reuse in California, USA)	UF	Ultrafiltration
GWRS (2)	Groundwater Replenishment Scheme (potable reuse project in WA)	UV	Ultraviolet
H₂O₂	Hydrogen peroxide	UOSA	Upper Occoquan Service Authority
IPR	Indirect potable reuse	WCRWS	Western Corridor Recycled Water Scheme
LRV	Log Reduction Value	WHO	World Health Organization
MCDA	Multi-criterion decision analysis	WSP	Water Safety Plan
		WWTP	Wastewater treatment plant

Glossary of Water Reuse Terminology

Advanced water treatment plant (AWTP)	Usually used to describe a plant that applies additional treatment to the effluents produced by a WWTP in order to further remove contaminants (typically by treatment processes which may involve activated carbon, membrane filtration, UV disinfection, advanced oxidation and others).
<i>De facto</i> potable reuse	A situation in which (treated) wastewater is discharged to the environment in such a way that it subsequently contributes to a raw drinking water supply. The term ' <i>de facto</i> ' implies that this situation occurs without being formally recognised as a planned potable reuse project.
Direct potable reuse (DPR)	Highly treated recycled water is delivered to a drinking water supply system without first being subjected to some significant pathogen reduction in an environmental water storage such as an aquifer, lake or large river system.
Engineered storage buffer	An artificially constructed water storage (a tank, reservoir or pond) used for the purpose of storing water, principally to balance variations in supply and demand for reclaimed water.
Environmental buffer	A natural water system (a river, lake or aquifer) in which reclaimed water is stored before being recovered for indirect potable reuse (IPR).
Groundwater replenishment:	A process of engineered replenishment of a groundwater aquifer with recycled water. Aquifers may be replenished by the use of infiltration basins or pressurised injection wells.
Indirect potable reuse (IPR)	Highly treated recycled water is delivered to a drinking water supply system after first being subjected to some significant residence time in an environmental water storage such as an aquifer, lake or large river system.
Non-potable reuse	The reuse of recycled wastewater for a purpose other than adding it to a drinking water supply. Common examples include agricultural irrigation and industrial applications.
Potable reuse	The use of highly treated recycled water as a drinking water supply.
Potable water recycling	Synonymous with potable reuse.
Potable water	Water that is suitable for drinking.
Purified Recycled Water (PRW)	Highly treated water for potable reuse (terminology commonly adopted by agencies in Queensland).
Reclaimed water	Water that has been recovered from wastewater by treatment processes sufficient to prepare it for reuse.
Recycled water	Reclaimed water that has been reused as a component of a drinking water supply.
Surface water augmentation	A process of engineered replenishment of a surface water system with recycled water.
Unplanned potable reuse	Synonymous with <i>de facto</i> potable reuse.
Wastewater treatment plant (WWTP)	A plant used to treat municipal (and/or industrial) wastewater, usually to a quality considered suitable for environmental discharge.
Water recycling	The reuse of recycled wastewater for the same or a similar purpose for which it was previously used. Depending on the context, may imply potable reuse.
Water reuse	The reuse of recycled wastewater for a suitable purpose in favour of disposal. Includes potable reuse and non-potable reuse.
Water treatment plant (WTP)	Usually used to describe a plant that is used to treat conventional water supplies for drinking water production (typically by treatment processes which may include coagulation, flocculation, media filtration, chlorine disinfection and others).

1

Introduction

Throughout the world, treated and untreated municipal wastewaters are discharged to waterways including streams and rivers. In many cases, towns and cities downstream draw upon such streams and rivers for municipal drinking water supplies. As such, water that was discharged as treated wastewater is indirectly reused for drinking water supplies. This practice is commonly termed 'unplanned' or 'de facto' potable reuse, indicating that although it is not usually seen as an intentional water supply strategy, it is nonetheless, a reality in many places (Rice & Westerhoff, 2015).

Planned potable water reuse involves the purposeful addition of highly-treated wastewater (i.e., reclaimed or recycled water) to a drinking water supply. The distinction between 'de facto' and 'planned' potable reuse is significant since the acknowledgement of intention and more holistic view of the overall urban water cycle has led to changes in implementation (Drewes & Khan, 2011). These changes have included increased attention to health risk assessment and management. In turn, these have led to the incorporation of enhanced or additional water quality treatment barriers in some cases (Drewes & Khan, 2015).

Since the 1990's, global interest in potable reuse has grown in many parts of the world. This has been facilitated by a number of key technical assessments, research and subsequently, policy and legislative developments.

An important milestone was the publication of a report by the US National Research Council titled 'Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water' (National Research Council, 1998). The technical and scientific concepts described in that report were further updated with the publication of 'Water Reuse: Potential for Expanding the Nation's Water Supply through Reuse of Municipal Wastewater' (National Research Council, 2012). Most recently, the US Environmental Protection Agency produced the 'Potable Reuse Compendium', providing a comprehensive summary of the status of potable reuse, including detailed assessment of research and policy developments in the USA (US Environmental Protection Agency & CDM Smith, 2017).

Ongoing research to advance technical capabilities has been supported by many international industry and government funded agencies in the USA (e.g. The WaterReuse Foundation, The Water Environment & Reuse Foundation, and The Water Research Foundation), South Africa (e.g. The Water Research Commission), and Australia (e.g. The Australian Research Council, The National Water Commission, The Australian Water Recycling Centre of Excellence, and WaterRA).

With over 50 years of practical experience, planned potable reuse has become an important water supply management strategy for a growing number of towns and cities around the world. The World Health Organization (WHO) has recognised that "*potable reuse represents a realistic, practical and relatively climate independent source of drinking water*" (WHO 2017). However, the WHO went on to say that "*potable reuse schemes will be complex and proponents will need to have sufficient resources and capabilities for successful implementation*". For this reason, it is necessary for any jurisdiction contemplating the development of a potable reuse project to equip themselves with a robust understanding of global experiences, use these to inform an appropriate regulatory approach, and apply this to the current status of 'best practice' for project design and management.

The purpose of this report is to provide a current update of the global status of planned potable reuse as a water supply strategy. It is intended that this may be of value to Australian decision makers and their advisors, as they consider appropriate policies for future drinking water supply augmentation and management. Furthermore, it should assist decision makers in providing relevant, accurate and current information to community members.

This report is not intended to provide descriptions of all planned potable reuse projects or all details of their regulation or management. However, it is intended to provide an overview of some of the most significant planned potable reuse projects, including a broad coverage of the key variable features among projects, such as the inclusion of groundwater recharge, surface water augmentation or direct potable reuse. Various approaches to risk assessment and regulation have developed among different jurisdictions and the general discussion of the main features is provided.

The success of any proposed potable reuse project depends significantly on effective community engagement for its planning and development. This is a lesson that has been learnt the hard way on a number of occasions. Thus this report provides an overview of some of the key factors that have been shown to influence community perspectives and ultimately, acceptability of proposed potable reuse projects. The provision of appropriate information, along with the timing and language used are examples of influential factors.

2

Global Status of Planned Potable Reuse Projects

A range of planned potable reuse schemes, employing various natural and engineered treatment processes, have been developed internationally since the early 1960s (Drewes & Khan, 2011). Some of the most prominent examples are summarised in this chapter in order to provide an overview of the extensive history and current status of planned potable reuse as an enhanced water supply strategy. More details, with references for each of these projects, are presented in Appendix 1 “Global Examples of Planned Potable Reuse”.

This section provides insight into the diversity of successful potable reuse projects with an aim to highlighting that variations in design can be made to better match the technological solution to the situation. An immeasurably important element of scheme success is public engagement and discussion of this is left in detail until Chapter 7.

The applications of planned potable reuse, commonly described as “groundwater replenishment” and “surface water augmentation” are examples of what has been commonly referred to as “indirect potable reuse” (IPR). A distinguishing characteristic of IPR is that recycled water, following some initial treatment, is returned to an environmental system where it mixes with ambient water, prior to being re-extracted and further treated for potable use. The environmental system for a groundwater replenishment project is the underground aquifer. The environmental system for a surface water augmentation project is most commonly a lake (such as the Occoquan Reservoir and its associated river system), though the definition could also be satisfied by a large river system alone. Direct potable reuse (DPR) does not include an environmental buffer for the recycled water prior to its addition, and possible further treatment, in the potable water supply system.

Compared to IPR, DPR projects have a number of additional challenges to overcome in order to compensate for the absence of various benefits which have been attributed to the environmental buffers of IPR projects. A survey of water industry practitioners in Australia (including utility personnel, industry bodies, academic organisations, state government departments and agencies, health regulators, local government organisations, Commonwealth Government departments and agencies) sought to gain an understanding of what roles people attributed to environmental buffers in IPR projects (ATSE 2013).

Some of the survey respondents indicated that they considered that environmental buffers serve negligible purpose. However, in response to open-ended questions, others indicated a broad range of purposes. Some of these related to technical benefits for water quality and safety, while others related to public perception of the potable reuse project. Depending on the nature of the environmental buffer, technical benefits can include improved water quality as a consequence of natural treatment processes,

as well as dilution, reducing the concentrations of chemical and microbial contaminants. A further important technical benefit is that an environmental buffer can provide ‘time to respond’ to treatment malfunctions or unacceptable water quality. In terms of public perception, environmental buffers were believed to provide a perception of increased water quality or safety. Furthermore, it was proposed that environmental buffers provide a perception of a disconnection between treated effluent and raw drinking water, which may be effective to reduce the “yuck factor” (see Chapter 7).

2.1 Planned potable reuse by groundwater replenishment since 1962

Groundwater replenishment has been the principal mechanism for IPR in California for over half a century. Cities in other parts of the world, such as Wulpen in Belgium, have more recently begun to emulate the successes from California. A groundwater replenishment scheme is also operating in Perth, Western Australia, however this is discussed later in Section 2.7.2.

2.1.1 California, USA

Potable water supplies have been intentionally replenished with recycled water in Los Angeles County of California since 1962 (Gasca & Hartling, 2012). This has been accomplished by the Montebello Forebay Groundwater Replenishment Project, located within the Central Groundwater Basin in Los Angeles County. This pioneering potable reuse project was developed in response to rapid population growth and over-extraction of the groundwater table. Groundwater over-extraction became severe during the 1950s, resulting in seawater intrusion into the aquifer.

The Montebello Forebay project was initiated by the use of secondary treated (conventionally treated) sewage, which was then disinfected with chemical disinfectants and used to recharge the groundwater aquifer at constructed spreading grounds (infiltration basins). In 1977, the treatment processes were upgraded to include media filtration to enhance virus inactivation during chemical disinfection. In the early 2000s, the plants were further upgraded to improve the removal of nitrogen from the water. In 2011, ultraviolet (UV) disinfection was installed for enhanced pathogen control.

Water is percolated into the groundwater using two sets of spreading grounds, the Rio Hondo and the San Gabriel Coastal Spreading Grounds. The operational conditions for the scheme have changed somewhat over the decades. However, current requirements allow up to 50% recycled water (which includes

both treated municipal wastewater and urban stormwater) to be recharged in any one year providing that the running three year total does not exceed 35% recycled water. This water contributes to the groundwater supply in Los Angeles County.

Following the success of the Montebello Forebay project, another major groundwater replenishment project established in neighbouring Orange County, California. The Orange County Water District developed what was known as “Water Factory 21” in 1976 (Wetterau *et al.*, 2013). The Water Factory 21 project sourced water from a municipal wastewater treatment plant (WWTP) and provided further treatment by reverse osmosis since 1977. In 2001, the treatment was further upgraded to incorporate high energy UV treatment for the destruction of a chemical contaminant, N-Nitrosodimethylamine (NDMA).

The Water Factory 21 plant was decommissioned in 2004 due to the need to expand capacity and to introduce updated treatment technologies. Construction of the Groundwater Replenishment System (GWRS) was subsequently jointly funded, and now operated, by the Orange County Water District and the Orange County Sanitation District of Fountain Valley, California. It takes wastewater that would have previously been discharged into the Pacific Ocean and purifies it by microfiltration (MF), reverse osmosis (RO) and advanced oxidation using UV radiation and hydrogen peroxide (UV/H₂O₂). The recycled water is then used to recharge underground drinking water supplies in Orange County, California.

Operational since 2008, with a capacity to produce up to 350 ML of recycled water per day, the GWRS is currently the world's largest water purification system for potable reuse. There are now plans in place to expand this to a production capacity of 500 ML/day. Construction for this expansion is expected to begin in 2019 and to be completed by 2023.

Approximately half of the recycled water currently provided by this facility is applied to surface spreading basins, and the remainder is used to maintain injection wells of the Talbert Gap Barrier to protect an important groundwater aquifer from seawater intrusion by the Pacific Ocean.

2.1.2 Belgium

The practice of potable reuse by groundwater replenishment has also been adopted in the city of Wulpen, Belgium. In the western part of Belgium's Flemish coast, groundwater is pumped from the unconfined St-André aquifer for drinking water supply by the Intermunicipal Water Company of Veurne-Ambacht (IWVA). However, in the 1990s, rapidly growing water demand had produced an overdraft on the aquifer. The groundwater level was dropping and there were growing concerns regarding the potential for saline intrusion to the aquifer.

The IWVA developed a plan to recharge the aquifer using recycled water from the Torreele WWTP in Wulpen (Van Houtte & Verbauwhe, 2013). In 2002, the Torreele facility was upgraded for water reclamation, further treating the secondary effluent by advanced treatment using ultrafiltration and reverse osmosis. An extra treatment with a UV disinfection system is possible as backup disinfection unit when needed.

The purified recycled water (7 ML/day) is recharged to the aquifer via an infiltration pond in the dunes of St-André (Van Houtte & Verbauwhe, 2012). The average residence time in the aquifer is around 55 days (Vandenbohede *et al.*, 2008). The recovered water is then conveyed to the potable water production facility at St-André which consists of aeration, rapid sand filtration, storage, and UV disinfection prior to distribution. Note that chlorine disinfection is not routinely used, but chlorine can be dosed when needed to prevent regrowth and recontamination in the distribution network. Since the project started, 35 to 40% of IWVA's annual drinking water demand has been met by the combined of reuse/recharge system.

2.2 Planned potable reuse by surface water augmentation since 1978

Not all municipalities with an interest in potable reuse have access to a significant, rechargeable aquifer for drinking water supplies. Cities relying on surface water storages for drinking water supplies have successfully developed the alternative strategy of 'surface water augmentation'. Examples are described here for projects developed in Virginia (USA) and Singapore. Rapidly emerging interest is described for surface water augmentation in California (USA). An Australian scheme, known as the Western Corridor Recycled Water Scheme (WCRWS) is described later in Section 2.7.1.

2.2.1 Virginia, USA

The pioneering potable reuse project to use surface water augmentation in the USA was led by the Upper Occoquan Service Authority (UOSA) in Virginia (Angelotti & Grizzard, 2012). Motivated by population growth, increasing urbanisation, and a declining water quality of the Occoquan Reservoir, the major raw water supply for northern Virginia, the UOSA water reclamation system was established in 1978.

The Occoquan Reservoir is a critical component of the water supply for approximately 1.5 million residents of Northern Virginia, a highly-urbanised region located west of Washington, DC. By the mid-1960s, increasing urbanisation was adversely affecting water quality of the reservoir, resulting in an unplanned and unintended

indirect potable reuse scenario, where 11 small WWTPs were discharging wastewater upstream of the reservoir. This type of scenario is now commonly referred to as ‘*de facto* potable reuse’.

In 1971, the Virginia State Water Control Board and the Virginia Department of Health established a plan to protect the Occoquan Reservoir as a drinking water supply. The Occoquan Policy mandated a new framework for water reuse and underscored the establishment of the first planned and intentional use of recycled water by surface water augmentation in the USA (State of Virginia, 2018). While water quality improvement was the primary driver for implementing planned potable water reuse in the Occoquan system, and hence recognising that *de facto* potable reuse was problematic, supplementing the raw water supply was also an underlying objective (Angelotti & Grizzard, 2012).

Prior to surface water augmentation, the water reclamation processes now include secondary treatment with biological nitrogen removal. Lime precipitation and clarification are used to remove phosphorus and also act as barriers to pathogens and heavy metals. Additional treatment is provided by multimedia filtration, granular activated carbon (GAC) adsorption and chlorine disinfection. The current water reclamation facility has a capacity of 200 ML/day.

Recycled water from the UOSA facility is discharged into a tributary of the Occoquan Reservoir. The discharge point is approximately 10 km upstream of the headwaters of the reservoir and 30 km upstream of the drinking water supply intake. Recycled water typically accounts for less than 10% of the annual average inflow to the reservoir, but during drought conditions may account for up to 90%.

Water drawn from the Occoquan Reservoir is treated at a drinking water treatment plant, for which a complete replacement (incorporating an upgrade) took place in 2006. The drinking water treatment processes now include enhanced metal salt coagulation, flocculation and settling, ozonation, biological activated carbon filtration and chloramination. Currently, the drinking water plant has a treatment capacity of 450 ML/day.

2.2.2 Singapore

A further major milestone for planned potable reuse by surface water augmentation was passed in 2003, with the establishment of two advanced water treatment plants (AWTPs) at Bedok and Kranji in Singapore. Since then, additional plants were constructed in Singapore at Seletar in 2004 (decommissioned in 2011, in line with the Urban Redevelopment Authority Master Plan for land use), Ulu Pandan in 2007 and Changi in 2010. These potable reuse plants were developed as part of a broad water supply expansion program for Singapore,

which has also included the development of urban stormwater reuse and seawater desalination.

The Singapore AWTPs were based on the treatment train previously developed for the ‘Water Factory 21’ project in Orange County, California. They include micro- or ultra-filtration, reverse osmosis and UV disinfection. The Singapore Public Utilities Board (PUB) has branded the potable recycled water produced from these plants as ‘NEWater’.

Since NEWater has ultralow dissolved salt concentration, it is ideal for processes that require highly purified water. Thus NEWater is primarily supplied to Singapore’s industrial sector such as to silicon wafer fabrication plants and to commercial buildings for industrial air-cooling purposes. It is also supplied to electronics and power generation industries. However, during dry periods, some 110 ML/day of NEWater are used to replenish surface water reservoirs prior to conventional drinking water treatment with an annual average of 30 to 40 ML/day. Together, Singapore’s four NEWater plants can meet approximately 30% of the nation’s (potable and non-potable) water needs, which presently total around 2,000 ML/day. By 2060, Singapore PUB plans to expand capacity so that NEWater can meet up to 55% of projected future demand.

Singapore’s success with water reuse has been well-documented and much discussed in the global water community, most notably in the area of securing public acceptance through a comprehensive and wide-ranging public communications programme targeting various groups of stakeholders (Lee & Tan, 2016).

A central aspect of the public education strategy was the establishment of the NEWater Visitor Centre, a very modern and high-tech water museum that acts as a centre for information regarding how NEWater is produced and the part it plays in Singapore’s water strategy. The centre allows visitors to view the treatment process at the Bedok NEWater factory from a gallery and understand the science behind it through interactive displays, tours and workshops. The centre is open to community groups, individuals and foreign visitors. It has also become part of Singapore’s National Education Programme, with regular visits from school groups. Singapore aims to have every child visit the facility during their primary school education. Allowing the public greater access to the ‘nuts and bolts’ of water reclamation has fostered trust and a sense of assurance (WHO 2017).

2.2.3 California, USA

Until recently, Californian regulations (see Section 5.1.1) did not include provisions for potable reuse by surface water augmentation. However, such provisions were developed and added to the regulations in anticipation of a number of major developing projects. The most prominent of these has been for the City of San Diego.

Around 80% of the water supply used by the City of San Diego is currently imported from distant sources, including the California Bay-Delta between San Francisco and Sacramento, and the Colorado River, and conveyed over large distances via piped aqueducts (Steirer & Thorsen, 2013). Both of these major import sources are increasingly subjected to restrictions, which has forced the city to examine other options for water supply.

San Diego City had failed to effectively gain sufficient public support for an earlier potable reuse proposal in the late 1990s. In the years that followed, events and organisations that targeted social awareness and community engagement as well as looking at the financial impacts to businesses as a result of water scarcity, were cited as responsible for reducing opposition in public opinion from 63% in 2004 to 25% in 2011 (Barringer, 2012).

In exploring the opportunities and feasibility for a potable reuse project, the city established the San Diego Water Purification Demonstration Project during 2009 to 2013 (Wetterau *et al.*, 2013). The key aspect of that project was the construction and operation of a 4 ML/day demonstration/pilot plant known as the 'Advanced Water Purification Facility' (Steirer & Thorsen, 2013).

In 2014, the San Diego city council voted unanimously for a plan to construct a full-scale potable water recycling project to recycle over 110 ML/day by 2023 (Phase 1) and over 310 ML/day by 2035 (Phases 2 and 3). This project has been branded 'Pure Water San Diego' and is expected to provide a third of San Diego's water supply when all phases are complete.

Construction of Phase 1, to supply the North City areas of San Diego will start in 2019. An advanced water treatment facility will supply recycled water, which will be piped to the Lake Miramar in the northern suburbs of San Diego. Miramar is a small lake, largely surrounded by urban development, which is used as a holding reservoir for San Diego's imported water sources, prior to treatment at the adjacent Miramar Water Treatment Plant, and distribution to customers. In planning for Phase 1, it was initially considered to send the recycled water to the much larger San Vicente Reservoir. However, that would have required a pipeline of 45 km from the North City Pure Water Facility, instead of 13 km to Lake Miramar.

The San Diego project is an IPR project and the Pure Water Program will become a model for the application of potable reuse by surface water augmentation in California, following the recent update California's Title 22 Code of Regulations to facilitate this (See Section 5.1.1).

Phases 2 and 3 will involve the development of two additional AWTPs, one to serve the Central Area of San Diego and the other in the southern region, known as South Bay. Water from the Central Area plant will be piped to the small, urban Lake Murray, and some

possibly on to the larger and more distant San Vicente reservoir. Water from the South Bay plant will be piped to the Lower Otway reservoir. Plans for Phases 2 and 3 may evolve over time and may be impacted by the establishment of Californian criteria for DPR through raw water augmentation, due before the end of 2023.

2.3 Direct potable reuse in southern Africa since 1968

Southern Africa saw the development of DPR long before other parts of the world considered the concept to be feasible. For most of the history of DPR, The City of Windhoek in Namibia has been the only example able to be named. However, since 2010, a number of projects have been proposed in South Africa, with one, in Beaufort West, being fully developed. Plans incorporating DPR for other parts of South Africa, such as the eThekweni Municipality (which includes the City of Durban and surrounding towns) and the town of Hermanus on the Western Cape, have been produced, but those projects are yet to be developed (ATSE 2013).

2.3.1 Namibia

Since 1968, the City of Windhoek in Namibia has pioneered DPR with the commissioning of the Goreangab Water Reclamation Plant.

Namibia is located in the south-western part of Africa and is the most arid country south of the Sahara Desert. Windhoek is the capital and largest city in Namibia, located in the centre of the country. The city is situated on the *Khomas Highland* plateau, at around 1,700 m above sea level. This arid location is 300 km from the ocean and 700 km from the nearest perennial river. It has an annual average rainfall of 370 mm per year, almost all of which occurs in the six months of December to May. The population of Windhoek is around 400,000 and continues to grow due to migration from other parts of Namibia.

In 1958, the Goreangab Dam was constructed to supply water for Windhoek, along with a conventional water treatment plant, known as the Goreangab WTP. However, the supply to this plant was found to be unreliable. In 1968, the Goreangab water treatment plant was converted to treat wastewater from the city's Gammams WWTP as an additional source to the Goreangab Dam. The plant was thus renamed the Goreangab Water Reclamation Plant, treating municipal wastewater blended with raw surface water, with an initial capacity of around 4 ML/day. This plant was upgraded several times and the capacity was ultimately extended to around 7 ML/day.

During the early 1990s, it was determined that additional capacity and improved water quality would be required in the future. A new plant, known as the New Goreangab Water Reclamation Plant (NGWRP) was then completed in 2002. The treatment train

consists of coagulation/flocculation, followed by dissolved air flotation and media filtration. The water is subsequently treated by ozone/hydrogen peroxide followed by biologically activated carbon (BAC) filtration. A final barrier is provided by ultrafiltration prior to final stabilisation and chlorine disinfection.

The NGWRP has a capacity of around 8 GL/year, and is approved to provide up to 35% of the total water supply on an ongoing basis and up to 50% during severe drought conditions. The City of Windhoek owns the plant, but its operations are contracted out to the Windhoek Goreangab Operating Company, an international private partnership company. The 20-year contract is managed through a private management agreement.

In 2019, there are now plans to expand the capacity of the Gammams WWTP, which provides source water to the NGWRP. The City of Windhoek has engaged consulting services for the development of an advanced treatment drinking water plant at Gammams to follow the newly expanded wastewater treatment processes. Consequently, it is anticipated that potable water reuse will be an increasingly important component of overall drinking water supply in the near future.

2.3.2 South Africa

The long-term successful experience with DPR in Namibia was undoubtedly a source of inspiration for a more recent potable reuse project, constructed in Beaufort West, South Africa. Beaufort West is situated in central Karoo, approximately 500 km north-east of Cape Town. It is one of the driest areas in South Africa, with an annual average rainfall of about 160 mm. There are roughly 40,000 inhabitants in Beaufort West Municipality spread across three towns, one of which is Beaufort West.

In 2010, a severe drought nearly depleted the town's raw water sources, resulting in an immediate shortage of drinking water. By 2011, the town was relying on trucks delivering additional drinking water to support its inhabitants. At that time, 5 L of drinking water per person per day were being trucked to over 8,000 homes. This situation led to the construction, in 2011, of a DPR plant known as the Beaufort West Water Reclamation Plant (BWWRP).

Subsequent to conventional tertiary treatment, the additional treatment processes used at the BWWRP include UF, RO, UV/H₂O₂ advanced oxidation and final chlorination. The plant is designed for a capacity of 2.1 ML/day. The recycled water is pumped to a 4.5 ML service reservoir 4 km away at a relative elevation of 100 m. The Municipality has three service reservoirs on the hill. The treated recycled water is fed into 'Reservoir 1'. The Municipality feeds conventionally sourced water (conventionally treated dam water and borehole water) to 'Reservoir 3'. The Municipality then blends approximately 20% recycled water and 80% conventionally sourced water into 'Reservoir 2'. This mixed water is then distributed to the town.

2.4 Direct potable reuse in Texas, USA since 2013

Following the experience and lessons from Windhoek, Namibia, a number of small water-stressed cities in Texas, USA began to investigate and develop DPR projects from around 2010. The first developed was in Big Spring, which began operation in 2013. Another project soon followed in Wichita Falls and another is currently under development in El Paso.

2.4.1 Big Spring

Big Spring is a city of approximately 30,000 people, located in the Permian Basin, West Texas, USA. Water supply servicing to Big Spring is provided by the Colorado River Municipal Water District (CRMWD). Most of the water supplied is raw surface water from three reservoirs constructed on the Colorado River. These sources are supplemented by groundwater reserves, but in the early 2000s it was apparent that additional supplies would be needed to meet growing demand and to offset apparent reductions in reservoir yields. An alternative source of water was identified in the wastewater produced by the Big Spring WWTP.

Careful consideration was given to a number of potential ways to make use of the WWTP effluent, including non-potable reuse, IPR and DPR. It was recognised that potable reuse would offer an opportunity for year-round use, reduced transmission distance and an improvement in raw water salinity. Several locations in Texas had previously developed plans for IPR. However, IPR was not considered to be as well suited to the Permian Basin area, due to high evaporative losses and the salt concentrations in both the current surface water and in available wastewater sources.

The implemented DPR project sources secondary effluent from the Big Spring WWTP and transfers it to an AWTP, where it undergoes treatment by microfiltration, RO and UV/H₂O₂ advanced oxidation. The treated water is then blended with raw surface water in the CRMWD's water transmission pipeline. Project construction began in June 2011, with blending operations having begun in April 2013. This facility is now known as the Big Spring "Raw Water Production Facility" (RWPF), emphasising its role in providing additional source water for the existing drinking water filtration plant.

The Big Spring RWPF has a capacity to produce up to 7 ML/day and it contributes up to 15% of the blended water in the existing pipeline network supplying CRMWD's member and customer cities including Big Spring. These cities operate conventional surface water plants which continue to provide final treatment, including disinfection, prior to drinking water distribution to customers.

In terms of engineered storage buffers, the RWPF includes about 2 ML of product water storage, which represents 6-7 hours at full production. After blending and prior to potable water treatment, the water is transferred to a 60 ML balancing reservoir. This is an open, earthen reservoir, which was constructed to allow mixing and equalisation for a number of raw water sources at a strategic junction in the system. It was in place before the reclamation project was conceived, and although it does represent storage and potential delay before proceeding to final treatment and distribution, it is not monitored or controlled for that purpose.

2.4.2 Wichita Falls

Following the development of the Big Spring project, a number of other DPR projects have been approved in Texas. One of these was the temporary DPR project, which was developed for the City of Wichita Falls. In mid-2013, Wichita Falls was under drought emergency conditions with the major surface water supply (Lake Arrowhead) diminished to less than 35% of capacity. In response, the city developed a two-phased approach to potable reuse. The long-term objective was an IPR scheme, which now operates and involves returning advanced treated wastewater from the city's 'River Road' WWTP to Lake Arrowhead. However, this project required the securing of a discharge permit, which the city had estimated to take four to five years to obtain.

In the interim, the temporary Wichita Falls DPR project was developed and brought online in July 2014. This involved taking the wastewater from the River Road WWTP, and delivering it to an AWTP located at the existing Cypress Water Treatment Plant. There, the water underwent treatment by MF and RO. It was then discharged to an engineered holding lagoon, where it was blended with surface water from Lake Arrowhead at a ratio of approximately one-to-one. The blended water was then treated by conventional drinking water treatment processes at the Cypress Water Treatment Plant. The DPR project got the city through an intense drought period, before the project could be converted to a permanent IPR project. It was successfully operated for 12 months, before being shut off in July 2015 following heavy rainfall.

Wichita Falls was operated first as a DPR project and then converted to an IPR project due to an urgent need for water and the fact that most of the infrastructure for DPR (including an underutilised brackish water MF/RO plant) was already available. However, the use of MF/RO for DPR results in the production of a waste brine solution and an overall reclaimed water recovery of approx. 70%. The final IPR design and configuration does not include RO treatment, which allows close to 100% water recovery. The IPR plant went online in early 2018, at which time the River Road WWTP was formally renamed the City of Wichita Falls Resource Recovery Facility.

2.4.3 El Paso

Continuing interest in DPR in Texas is exemplified by planning currently underway by the City of El Paso in west Texas. With a population of 700,000 and rapidly diminishing local water resources, El Paso has adopted numerous innovative responses for water supply (Maseeh *et al.*, 2015). The City has been practicing IPR by groundwater infiltration since the mid-1980s (Sheng, 2005), but since around 2013, the city has been planning for DPR (Maseeh *et al.*, 2015).

In 2016, El Paso Water completed a pilot test for an AWTP. Following the successful piloting, the Texas Commission on Environmental Quality gave El Paso Water approval to proceed with design of the full-scale facility. Thus the design for a full-scale AWTP to produce water of up to 38 ML/day is currently underway. Unlike other DPR facilities in the United States, which return drinking water to a treatment plant, the El Paso Facility is proposed to use a direct-to-distribution approach, with the recycled water flowing directly into the drinking water distribution system.

2.5 Planning for direct potable reuse in California

During 2007-2009, the US State of California experienced the 12th worst drought period since the state's recorded history and the first drought for which a state-wide proclamation of emergency was issued. This period also saw greatly reduced water available to Southern California from the state's major water diversion program, known as the California State Water Project.

In response to these conditions, the Governor of the State of California signed into law Senate Bill 918 in 2010. This was an Act to provide amendments and additions to the California Water Code, specially relating to potable reuse. This Senate Bill required the California Department of Public Health to investigate the feasibility of developing regulatory criteria for DPR and to convene an expert panel to study the technical and scientific issues. A final report was produced for the Legislature with the expert panel having found that it is technically feasible to develop uniform water recycling criteria for DPR in California, and that those criteria could incorporate a level of public health protection as good as or better than what is currently provided by conventional drinking water supplies and IPR (California State Water Resources Control Board, 2016).

A Californian Assembly Bill, introduced in 2017, now requires the Californian State Water Resources Control Board to adopt uniform water recycling criteria for DPR by the process of 'raw water augmentation' before the end of 2023 (extendable by up to 18 months) (see Section 5.1.2). Raw water augmentation was defined

to mean 'planned placement of recycled water into a system of pipelines or aqueducts that deliver raw water to a drinking water treatment plant that provides water to a public water supply system'.

To do this, the State Board must establish an expert review panel and the panel must find that the proposed criteria would adequately protect public health, before any such criteria may be adopted. Furthermore, the Bill stated that the State Board should establish a framework for the regulation of potable reuse projects by June 2018. In response to this requirement, The Californian State Board produced a proposed framework for regulating DPR in California (California State Water Resources Control Board, 2018).

A number of Californian cities are closely observing the development of these criteria for DPR and some have publically identified potential future projects. One example is the City of Ventura on California's Central Coast.

Drinking water for Ventura is sourced from the Ventura River, Lake Casitas, and local groundwater basins. In times of minimal rainfall and drought, water levels drop and these supplies become limited. Unlike nearby Southern Californian cities (Los Angeles and San Diego), Ventura does not have access to imported water supplies.

Ventura Water Pure, the city's new potable reuse project, has been developed with a plan to increase Ventura's drinking water supply and help to sustain the city's existing water resources. The project has included the construction of the *VenturaWaterPure* demonstration facility, providing treatment to recycled water by MF, RO and UV/H₂O₂ advanced oxidation. This facility was opened in 2015 with intention to demonstrate capacity to produce water for DPR.

It is proposed that following advanced treatment, recycled water produced by a future full-scale plant will be sent to the local drinking water treatment plant and mixed with water from Lake Casitas, the Ventura River, and local groundwater supplies before it is sent to homes and businesses. Such an arrangement, if designed appropriately, would meet the recently adopted Californian State definition for 'raw water augmentation'.

2.6 Growing interest in non-membrane treatment trains for potable reuse

Most of the major potable reuse projects, developed over the last few decades have relied upon RO membrane filtration as a key treatment process. This has been following the lead of the Orange Country Water Factory 21 project, which introduced RO to the treatment train in 1976. Other potable reuse projects in Singapore, the USA and Australia were subsequently modelled on this same treatment concept. However, a well-recognised limitation of RO treatment processes is the need to dispose of concentrated saline waste solutions. In coastal areas, this is usually managed by discharge to the ocean, but disposal options tend to be much more limited for inland areas. Efforts to avoid the production of significant concentrated waste streams have given rise to a number of alternative treatment trains, which do not incorporate high pressure membranes such as RO.

The Prairie Waters Project in Aurora, Colorado provides an example of a potable reuse project, which has successfully adopted a treatment train avoiding membrane treatment. In this case, source water is taken, not directly from a WWTP, but from the South Platte River, downstream from the Denver Metro Wastewater Reclamation District's WWTP.

The City of Aurora owns limited water rights to draw fresh water resources from the South Platte River Basin. While the total volumes, which can be extracted are limited, the City has the right to reuse its own treated wastewater, even once it has been discharged back into the river system. The Prairie Waters Project was conceived and constructed to capitalise on this opportunity to extract water downstream of the WWTP, without adding to the tally of legal water extractions (Aurora Water, 2016).

The first stage of the Prairie Waters Project involves recovering water from South Platte River, close to the city of Brighton. This water contains a high degree of wastewater discharge (>80%). As an initial purification step, a process of "riverbank filtration" was developed, as is relatively commonly used in some European cities, such as Berlin and Mainz. During this process, 23 extraction wells draw the water through a distance of sand and gravel river bank. A subsequent process of soil aquifer recharge is applied, whereby the water is pumped into infiltration basins where it percolates through more sand and gravel over a longer period of time, effectively extending the riverbank filtration process. The recovered water is then pumped, via a 60 km pipeline back upstream of Aurora to the 190 ML/day Peter Binney Water Purification Facility, adjacent to the Aurora Reservoir. Pumping stations lift the water almost 300 m on this journey.

Advanced water treatment at the Peter Binney Facility consists of partial softening, UV/H₂O₂ advanced oxidation, BAC filtration, and final GAC filtration. Subsequently, the water is blended in a ratio of 1:2 with Aurora's current supply (mountain run-off after conventional surface water treatment), disinfected with chlorine and delivered to the city's distribution system. Development of the Prairie Waters Project was initiated in 2007 and it was completed in 2010.

Another important potable reuse project, which avoids the use of high pressure membranes, such as RO is situated in Gwinnett County, Georgia, USA. This advanced treatment plant produces recycled water using low pressure ultrafiltration (UF) membranes, followed by ozone, biological activated carbon filtration and further ozonation (Funk *et al.*, 2018).

Lower costs were one factor resulting in an overall preference for a non-RO based treatment train for Gwinnett County. When the advanced water treatment flowsheet was compared to another plant in Oxnard California (UF-RO-UV/AOP) and both were scaled to treat 90 ML/day of wastewater, it was predicted that both the capital and operating costs of the ozone-BAC arrangement would be approximately 40% lower (Lozier, 2016). This study neglected brine disposal, hence the cost difference between both options in reality would likely be greater, if feasible and environmentally sustainable disposal options were available.

An additional benefit of the non-RO based arrangement is greater water recovery. GAC processes only lose a small fraction of recovery, proportional to backflush requirements. This is much less than the proportion of water disposed as brine in most RO applications.

The Gwinnett County treatment train was credited with 5.5 LRV for *Cryptosporidium* and 8 LRV for viruses. By contrast, the UF-RO-UV/AOP plant was credited with 11.5 LRV for *Cryptosporidium* and 8 LRV for viruses. Notably, 6 LRV for both *Cryptosporidium* and viruses was credited solely to the UV/AOP process in the Oxnard train. Thus, hypothetically, addition of a UV/AOP process to the treatment train at Gwinnett and assignment of 6 LRV would bring the *Cryptosporidium* LRV equivalent and the virus LRV above 14, when compared to a typical UF-RO-UV/AOP plant (Lozier, 2016).

2.7 Planned potable reuse in Australia

Australia has a chequered history with the development of planned potable reuse projects. Since the mid-1990s, there have been numerous projects proposed, many of which did not eventuate due to strident community opposition (Khan, 2009). Most notorious, was the failed proposal to construct a potable reuse project in the City of Toowoomba, Queensland, for which most of the planning took place during 2005-2006. A significant factor in that case was politicisation precipitated by the awarding of government funding, contingent on the outcome of a public vote, for or against the construction of the project (Hurlimann & Dolnicar, 2010a; Price *et al.*, 2012).

Nonetheless, valuable lessons were learned from the Toowoomba experience, relating to risk perceptions, the importance of building social trust and public acceptance of potable reuse (Dolnicar & Hurlimann, 2011; Ross *et al.*, 2014). These lessons have since been drawn upon by Australian water supply planners in the decade following the Toowoomba vote. Two major projects have now been developed, being the Western Corridor Recycled Water Scheme (WCRWS) in South East Queensland and the Groundwater Replenishment Scheme (GWRS) in Perth, WA.

2.7.1 Western Corridor Recycled Water Scheme (WCRWS), QLD, Australia

A very large potable reuse project was constructed in South East Queensland, with the intention of augmenting surface water supplies for the area, including Brisbane (Traves *et al.*, 2008). The WCRWS was designed in 2007 to use the vast majority of treated municipal wastewater produced in South East Queensland, collected from six WWTPs at Bundamba, Goodna, Oxley, Wacol, Luggage Point and Gibson Island (Walker *et al.*, 2007).

This treated wastewater was planned to be delivered to three AWTPs at Bundamba (60 ML/day), Luggage Point (70 ML/day) and Gibson Island (100 ML/day), where it would undergo advanced treatment by microfiltration, RO, UV-advanced oxidation and chlorine disinfection. The project was designed to produce a total recycled water supply capacity of 230 ML/day (Poussade *et al.*, 2009).

The AWTPs were interconnected into an overall system with extensive pipelines connecting the three plants and delivering the recycled water for intended reuse applications. They produced water for potable substitution to supply two nearby coal fired power stations, with a sizeable volume apportioned for potable reuse

by augmentation of the region's largest surface water reservoir, Lake Wivenhoe. However, shortly following construction in 2008, drought breaking rains reduced the immediate water shortage. While water continued to be produced for industrial use, the Queensland Premier announced that this additional water supply would no longer be needed for potable supply, as long as South East Queensland water storages remained at above 40% of their capacity. That trigger has not been approached during the decade since passed.

Comprehensive validation and verification testing during piloting and start-up of the facilities has been conducted (Roux *et al.*, 2010; WaterSecure, 2010). These activities demonstrated that the recycled water quality meets, and even exceeds, the requirements of the Australian Guidelines for Water Recycling (NRMCC, EPHC & NHMRC 2008) as well as the Australian Drinking Water Guidelines (NHMRC & NRMCC 2011).

Modelling undertaken in 2012 indicated that there was only a five per cent cumulative chance of the WCRWS being fully required by 2030 (Queensland Audit Office, 2012). The WCRWS ceased supply of water to the power stations at the end of 2013 and was placed in to 'care and maintenance' in 2015. Doing so was proposed to limit the annual increase on bulk water charges and therefore produce savings for household water customers. The scheme can be restarted when required as one of South East Queensland's drought response measures, assisting with long-term water security for the region.

In 2017, Seqwater produced Version 2 of its "Water for Life: South East Queensland's Water Security Program 2016-2046" (Seqwater, 2017). This document lays out a plan for how water supply security for the region will be maintained over the 30 year period. Among many diverse strategies, the WCRWS will start remobilisation if ever the combined South East Queensland key bulk water storages drop in volume to below 60% of their full capacity. The Restart Project involves the remobilisation and restart of the WCRWS to be delivering 180ML/day of recycled water to be available for augmentation of Lake Wivenhoe within two years from the restart trigger date.

Once a restart is triggered, Seqwater intends to bring the WCRWS back on line one plant at a time starting with Luggage Point to allow for the full remobilisation to be halted in the event of rain filling dams. This progressive approach will provide flexibility to adjust down (or cease incrementing) if rainfall leads to higher storage volumes in South East Queensland. Furthermore, it will enable the operational conditions of the assets to be ascertained as early as possible and facilitate early regulatory testing to assist and streamline the subsequent testing of the remaining scheme.

2.7.2 Groundwater Replenishment Scheme (GWRS), Perth, WA, Australia

The Groundwater Replenishment Scheme (GWRS) is an IPR project operated by Water Corporation of Western Australia. Located in the northern suburbs of Perth, the GWRS is a managed aquifer recharge project, designed to recharge important drinking water aquifers for the city. Treated wastewater is sourced from the Beenyup WWTP and further purified at an adjacent AWTP by ultrafiltration, RO and UV-disinfection. Recharge bores are used to deliver the recycled water to Yarragadee and Leederville aquifers. These aquifers provide a source of raw drinking water for Perth, which is then treated at conventional water treatment plants prior to municipal distribution.

Prior to commissioning, this project was preceded by an extensive groundwater replenishment trial (2010-2012), which also served as a basis for research, community information sharing, and for regulatory development with the relevant public health regulator, WA Department of Health. A 5 ML/day AWTP was constructed for the trial and the performance of this plant was validated during 2009 and 2010. The treated water produced by the plant was used to recharge the Leederville aquifer by direct injection throughout the three-year trial (Water Corporation, 2013). This water was recharged into the aquifer 120 to 220 m underground, at a location remote from any drinking water abstraction wells.

Following the successful completion of the Groundwater Replenishment Trial, the Western Australian Government announced that groundwater replenishment would become the next climate independent water source to secure Perth's drinking water supply (Redman, 2013). Stage 1 of the full-scale GWRS was constructed and commenced operations in 2017. This first stage has the capacity to recharge the Leederville and Yarragadee aquifers with up to 14 GL/year of highly treated wastewater.

The development of Stage 2 of the GWRS is currently underway with the construction of a second full-scale AWTP as well as construction of new recharge bores and associated recharge pipeline to the north-east of the Beenyup plant in Craigie. This second stage is expected to be completed during 2019 and will double the scheme's capacity to 28 GL/year. Water from Stage 2 will be recharged into the confined Leederville and Yarragadee aquifers via two recharge sites, one in Wanneroo and one in Neerabup. It is proposed that by 2060, groundwater replenishment could recycle 115 GL/year with water sourced from a number of WWTPs.

3

Drivers and Incentives for Potable Reuse

In this chapter, a distinction is made between the 'drivers' and the 'incentives' for potable reuse. The drivers are considered to be the pre-existing, underlying conditions that lead a community to recognise a need for change in the way that water supplies are managed. Common examples include observed or projected stresses upon current water supply availability. These might be forecast to increase with growing populations or changes in climatic conditions.

Once the drivers for potable reuse have been recognised, there may be a number of options available or steps that may be taken, to address them. The 'incentives' for potable reuse then are factors that enhance the attractiveness of potable reuse as an option of choice, against competing alternatives. Comparisons and choices between alternatives are made on the basis of key criteria, which may include such things as economic, environmental and social impacts. Thus the incentives for potable reuse will be defined by the performance of potable reuse against the key criteria, relative to the performance of competing alternatives. In all cases, these performances will be heavily influenced by local considerations encompassing geography, economic conditions and social characteristics.

3.1 Drivers for potable reuse

For the vast majority of planned potable reuse projects around the world, the key overriding driver has been the need to expand water supply capacity to meet growing demand. In some cases, this need has been exacerbated by long-term changes in conventional water supply availability, or by intense immediate drought conditions. In a few cases, the reality of a *de facto* potable reuse situation was recognised and a decision was made to upgrade that situation to one of planned potable reuse, implying improved water quality treatment and management. Another driver has been the opportunity to avoid major wastewater infrastructure augmentation costs. Each of these drivers may be expected to continue to underscore the development of potable reuse projects in Australia and internationally.

3.1.1 Need to expand water supply capacity to meet growing demand

Imbalances between supply capacity and demand have most directly been associated with population growth. In some cases, such as for the development of the WCRWS in South East Queensland, severe acute drought conditions have precipitated rapid response, including planning for potable reuse project development. In others, such as Perth, ongoing drying climate has provided the indication for a need for alternative sources, and

responses have not required the same degree of rapid planning and development. Other factors, such as loss of water catchment from increased urbanisation may also play a role in some circumstances.

Population growth can be expected to be an important driver for the development of new water resources for many Australian towns and cities over the coming decades. In a recent report developed to assist with planning for future cities, Infrastructure Australia stated:

"Australia's largest cities are facing a watershed moment in their growth and development. In the coming 30 years the size of the Australian population will grow substantially. Between 2017 and 2046, Australia's population is projected to increase by 11.8 million people. That's equivalent to adding a new city, roughly the size of Canberra, each year for the next 30 years" (Infrastructure Australia, 2018).

About 75% of this growth will occur in Sydney, Melbourne, Brisbane and Perth (Infrastructure Australia, 2018). In the next 30 years, Sydney's population is projected to increase by 2.4 million people (55%), growing to be a city of 7.4 million. Over the same period, Melbourne is projected to grow by 2.7 million people (60%), to be a city of 7.3 million. Brisbane is projected to grow by 1.6 million people (70%) and Perth by 2.2 million people (100%), delivering cities of just under 4 million and 4.3 million, respectively.

Infrastructure Australia identified urban water systems as one of the key areas for which these growing populations (and changing urban environments) would bring new challenges. The report notes that while proportional growth in apartments has reduced water consumption per dwelling, this shift has also concentrated demand in smaller areas. It states:

"Continued growth in urban populations will put increasing strain on sources of supply near our major cities and on legacy distribution networks within them. The majority of cost-effective sites for dams and wastewater treatment near cities have been used, and changes in rainfall patterns may reduce the available supply" (Infrastructure Australia, 2018).

The increasing – and more concentrated – demand for water resources, combined with a potentially reduced available supply, can be expected to be a strong driver for alternative water supply resources in coming decades.

Potable water reuse offers a potentially significant, relatively drought-proof¹ source of water. The degree of significance is, to a large extent, a consequence of the '*multiplier effect*' that comes with reclaiming water which, once reused and returned to municipal sewers, becomes available to reclaim a second and subsequent times.

The 'multiplier effect' is a term used widely in macroeconomics to describe the disproportional economic stimulus that may follow from an injection of new demand to an economy. It occurs because an injection of extra income leads to more spending, which creates more income, and so on. The multiplier effect refers to the increase in final income arising from any new injection of spending. The size of the multiplier depends upon households' marginal decisions to spend.

In the case of water recycling, an injection of 'new' water into a municipal system is made to meet new and growing demand. Some of that water (such as that used on gardens and other outdoor uses) will be lost from the system, but in a highly urbanised scenario, much of it will be returned to the sewage collection system and become available for retreatment and reinjection back into the system. A city which is able to capture and recycle 50% of the drinking water it supplies will capture 50% again (thus a total of 75%) on the second time around. Capturing 50% on the third time around gives a total of 88%. This practice of 50% capture and recycle will ultimately lead to a doubling (an extra 100%) of the city's available potable water supply. The impact of the multiplier effect becomes exponentially more effective as the percentage of water recapture and reuse increases (Figure 1).

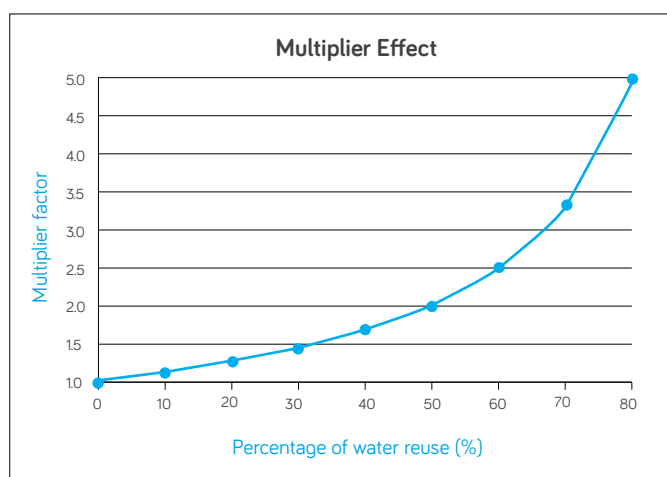


Figure 1: The 'multiplier effect' showing increased water availability as a result of closing the loop with increased proportions of potable reuse.

Note that while this multiplier effect does not apply to non-recycled water sources, seawater desalination can provide an effectively limitless supply and is climate-independent.

¹ Note that potable reuse is not always fully 'drought proof' since this supply is reliant upon sufficient volumes of wastewater generation. During periods of tight restrictions on water use, wastewater generation can be notably reduced, as was observed in South East Queensland during 2010 (Queensland Audit Office, 2012).

3.1.2 Conversion of *de facto* potable reuse to planned potable reuse

The Occoquan Reservoir is an important drinking water reservoir, supplying around 1.5 million residents of northern Virginia, USA. However, by the mid-1960s, the Occoquan Reservoir was subjected to a *de facto* potable reuse scenario, whereby 11 WWTPs were discharging treated wastewater into waterways upstream.

A more planned approach to potable reuse was established in 1971 by the 'Occoquan Policy', developed by the Virginia State Water Control Board and the Virginia Department of Health (State of Virginia, 2018). This Policy mandated a new framework for potable water reuse with water quality improvement as its primary objective (State of Virginia, 2018). This objective was initially addressed by enhanced treatment at the WWTPs prior to discharge to the reservoir. In 2006, the drinking water treatment plant, which draws raw water from the reservoir, was replaced with a new plant, also delivering a higher level of water quality treatment and control.

Another example where a potential *de facto* reuse scenario was converted to IPR was in Gwinnett County, USA. In this case, a new inland treated sewage outfall was proposed for installation in the proximity of a drinking water intake. One of the drivers to upgrade the technology at the upstream WWTP was to appropriately manage the health risk associated with the potential *de facto* reuse scenario. Had the plant not been upgraded, there would have been insufficient engineered controls to mitigate the risk downstream (Funk *et al.*, 2018).

Throughout the world, there are many examples of *de facto* potable reuse (Rice & Westerhoff, 2015; Wells *et al.*, 2017). Public awareness of such circumstances has grown during the last two decades with increasing reports of anthropogenic chemicals, including pharmaceuticals (Yang *et al.*, 2017; Riva *et al.*, 2018; Rosin *et al.*, 2018) and illicit drug residues (Peng *et al.*, 2016) in drinking water supplies.

Most examples of *de facto* potable reuse in Australia operate with tight water quality controls, focused particularly on nutrient removal to prevent eutrophication in receiving waters. Furthermore, the drinking water treatment plants must meet ADWG requirements and are subject to significant regulatory oversight to do so. Nonetheless, the regulation and oversight of these *de facto* potable reuse systems are different to what they would be if these scenarios were formally recognised as planned potable reuse projects. This situation may lead to an imbalance in the future, where planned potable reuse projects are subjected to different regulation, with different levels of water quality and safety, compared to *de facto* potable reuse scenarios. A desire to address this imbalance may prove to be a driver for planned potable reuse in future decades.

3.1.3 An opportunity to avoid major water or wastewater infrastructure augmentation

In some cases, the development of a potable reuse project may be motivated by the opportunity to avoid major augmentations to water or wastewater conveyance, treatment, or disposal infrastructure. Avoided augmentations to wastewater infrastructure could include the opportunity to avoid costs associated with marine disposal, such as ocean outfalls. Avoided water infrastructure augmentation could include the costs of developing alternative new supplies, such as new dams and long pipelines.

The City of San Diego has long held a wastewater discharge permit from the US EPA, enabling discharge of primary treated effluent from the Point Loma WWTP. However, primary treated effluent quality no longer meets increasingly stringent EPA requirements and there was a high possibility that the discharge permit would no longer be renewed in coming years. A demonstrated reduction in wastewater discharges was required by the EPA for the City to secure an ongoing permit. The City has reported that the development the San Diego Pure Water Program was motivated in part by the opportunity to save an estimated \$1.8 billion cost to upgrade the Point Loma WWTP to secondary treatment (City of San Diego, 2018).

Bega Valley Shire Council (NSW, Australia) have been investigating options for the disposal or reuse of wastewater from the Merimbula WWTP for a number of years. When undertaking an options assessment, the possibility of reusing the majority of available treated effluent for IPR was considered among a number of other options to minimise ocean discharge and potentially avoid the construction of a deep-water ocean outfall (BVSC 2013). However, the IPR option was relatively quickly dismissed citing (assumed) community objection to drinking recycled water.

3.2 Incentives for potable reuse

When there is a need to expand water supply capacity, most towns and cities will assess multiple implementation options. These might include the construction of new surface water storage and conveyance systems, new groundwater abstractions, decentralised rainwater tank networks, seawater desalination, as well as potable and non-potable water reuse options. An optimum solution, for a particular circumstance, may involve a heavy reliance on a single option or, more commonly, a 'water supply portfolio' encompassing numerous components of supply options. In this section, a number of water supply portfolio investigative case studies are cited to highlight the potential incentives for potable reuse.

A water supply portfolio should be established by the selection of individual components, which collectively meet an identified

supply need, with optimised performance against a number of key selection criteria. In most cases, these selection criteria will reflect triple-bottom-line considerations, encompassing (short term and long term) costs, environmental impacts and social impacts.

The availability of some potential options may be limited by geographic conditions. Seawater desalination is unlikely to be a viable option for cities that are inland or separated from coastal areas by significant elevation. Brackish groundwater desalination may sometimes be an option for inland areas, but usually only where sufficient conditions and available space are available for brine evaporation.

Similarly, the construction of new dams requires suitable geographic conditions, such as the availability of significant waterways running through river valleys amenable to dam construction for capturing and storing water. The use of long pipelines for inter-basin transfers of water is only possible where competing demands for the available water do not exceed the available supply. Even the development of potable or non-potable water reuse may require the harvesting of water for which existing demands (e.g., downstream of the discharge of a WWTP) may be significant.

Once a town or city has identified that there is a need to expand water supply availability, and has identified a range of technically viable approaches, there remains a need to compare the potentially available options in terms of how they perform against key criteria. The criteria themselves will vary from one location to another, but in most cases would normally be expected to include each of the following to a greater or lesser degree:

- Volumes of water (per period of time) expected to be available
- Reliability of the water supply, especially during drought conditions
- Capital costs for infrastructure construction (CAPEX)
- Ongoing operational costs (OPEX)
- Environmental impacts
 - Greenhouse gas (GHG) emissions
 - Impacts to waterways and terrestrial environments (positive or negative)
 - Lifecycle impacts (e.g. impacts from chemicals or materials use)
- Public health risks or benefits
- Social and political acceptability
- Impacts related to competing demands for water resources.

Impacts relating to each of these criteria may follow directly from the development of a potable reuse project, or may flow as a consequence of reducing other impacting activities such as effluent disposal to the environment. Receiving environments have limited capacity to assimilate treated effluent discharges and significant compliance costs are associated with managing the impacts. If a significant proportion of treated effluent is diverted away from environmental discharge then compliance costs can be avoided and/or the available assimilative capacity of the receiving environment can be used to support future growth.

Answering the question of which water supply solution (or combination of solutions) is most favourable is an example of multi-criteria decision analysis (MCDA) (Zarghami & Szidarovszky, 2011). Such an approach involves identification of the key criteria, identification of a short-list of options and assessing each of those options in terms of how they perform against each of the criteria. Relative measures of importance are attributed to each of the criteria and the criteria are normalised in such a way that they may be numerically compared in a meaningful way. An MCDA, such as this, may assist in decision making by framing the problem and indicating key relevant information required to undertake a comparison.

3.2.1 Design and life cycle comparison of water supply options

In 2013, Australian engineering company, GHD undertook a life-cycle based engineering assessment of a hypothetical scenario for a city wanting to compare four potential options for the expansion of water resources (GHD, 2013). Four hypothetical options were defined for alternative water supply to an urban city at a coastal location in Australia. The nominal total capacity of treatment and delivery systems for all options was an average of 120 ML/day of product water or at least 40 GL/year. The four hypothetical options considered were:

- Seawater desalination: Producing water that is fed into an assumed pre-existing potable water distribution system.
- Indirect potable reuse (IPR): Advanced water treatment, followed by surface water augmentation.
- Direct potable reuse (DPR): Advanced water treatment, followed by direct delivery to a conventional potable supply distribution system.
- Dual pipe reuse: Advanced treatment of secondary wastewater, followed by the use of a new dedicated distribution system for non-potable uses (e.g. toilet flushing and outdoor uses).

Flow-specific power consumption for the four options was modelled. Seawater desalination was determined to have the highest electricity

(power) consumption. Power consumption was dominated by that required for water production, which in turn is largely due to the higher osmotic pressure (and hence for reverse osmosis) of seawater compared to the other options. The water recycling options take feed in the form of treated wastewater at lower osmotic pressures, and hence require less energy for treatment.

Comparing IPR (by surface water augmentation) and DPR, IPR was found to require increased power consumption for product water delivery, due to the longer pipeline and higher discharge elevation for this option. However, despite this increase, seawater desalination retained higher power consumption on a flow-specific basis than IPR. It was concluded that IPR would approach seawater desalination in terms of power consumption on this basis if an IPR product delivery pipeline of significantly longer than 100 km was assumed in the modelled scenario. DPR was determined to have a lower flow-specific power requirement, as expected, given the shorter pumping distance for product delivery.

The dual pipe reuse scenario had the lowest flow-specific power requirement of the options considered, mainly due to the absence of reverse osmosis and shorter pumping distances with lower elevations assumed for product delivery in the local areas connected to the dual pipe recycled water network.

Comparison of the options on a flow-specific basis for GHG emissions, with a breakdown between GHG emissions Scope 1 (direct emissions from the activity), Scope 2 (e.g. from power consumption) and Scope 3 (e.g. embodied in construction materials and consumables) was undertaken. This assessment showed that the GHG emission profiles were dominated by electricity (power) purchased from the grid, which is the sole contributor to Scope 2. Scope 3 emissions made a bigger relative contribution for the options with the lower overall power requirement.

The desalination plant capital expenditure was determined to be relatively high compared to the other options, but given desalination plants are located in close proximity to the sea at sea level, a shorter transfer pipeline and lower head was required, resulting in considerably lower transfer system costs as compared to some of the other options. Note that this outcome assumes an availability of suitable land on the coast and close to the point of use. This assumption may not always be valid for large Australian cities.

Due to the longer distance specified to transfer recycled water from the point of wastewater collection and treatment to raw water dams as source of potable water, and the requirement to construct such a pipeline, the IPR option had a high transfer system cost which was the dominating cost factor for this option. The capital cost for dual pipe reuse was determined to be roughly equivalent to the IPR option.

Given the shorter connection to supply recycled water directly to the reticulation system for the DPR option, the (perhaps unlikely) assumption of no post-treatment storage, and essentially the same process treatment train as for the IPR option, the DPR was more attractive from a lower capital cost point of view.

The authors emphasised a key point in comparing among these different options (GHD, 2013):

“Pipelines are expensive and increase operating costs for energy also. So the location of treatment facilities and the network locations that they might connect to are significant, possibly even overriding factors in cost comparison. Hence, to some extent, option comparison will always be a location-specific consideration”.

To be able to realistically compare dual pipe recycled water plants to the larger alternative options presented, it was necessary to assume multiple smaller plants were located in close proximity to WWTPs. The dual pipe reticulation systems added significant capital expenditure for this option. This illustrates the point that additional reticulation is expensive and, based on the assumptions used in this assessment, that the additional reticulation costs significantly outweigh the cost reduction due to reduced treatment requirements.

On a whole-of-life cost basis, given the assumptions underlying the options defined for this investigation, seawater desalination and IPR were found to be comparable and have the highest costs. Direct potable reuse and dual pipe recycled water had lower and comparable costs.

3.2.2 Triple bottom line analysis to evaluate water supply options

A recent project undertaken for the US-based Water Research Foundation (with contributions from WaterRA and the Water Services Association of Australia) developed a quantitative framework to allow water utilities to conduct a triple-bottom-line (TBL) evaluation of direct potable reuse projects compared to other alternative water supply systems such as indirect potable reuse, groundwater or surface water development, desalination, and demand management, among others (Stanford *et al.*, 2018; Hadjikakou *et al.*, 2019). That project produced a quantitative modelling framework, packaged as the Water Supply Evaluation Tool (WaterSET), capable of computing impacts across multiple TBL indicators for a wide range of user-specified water supply options at the unit process level. WaterSET is a triple bottom line input-output based life cycle analysis that incorporates economic and environmental input-output analyses, lifecycle cost analysis, and social impact analysis into a single evaluation for the characterisation and ranking of water supply options.

WaterSET begins with a list of user-defined water supply options to be evaluated. Input data provided by the user are used by the model to calculate estimates of capital, operations and maintenance costs. The tool then calculates values for economic and environmental criteria using an input-output based hybrid – lifecycle analysis. Values for social criteria are calculated using a social impact analysis model. The full list of selected indicators considered by the tool is as follows:

- **Economic indicators:** Lifecycle cost, Income generation, Outside capital cost, Variable cost, Cost of imported inputs.
- **Environmental indicators:** Carbon footprint, Water footprint, Eutrophication potential, Eco toxicity potential, Land/space requirement, Residuals/brine disposal.
- **Social indicators:** National jobs created, Effect on human health, Drought resilience, Public acceptance, Social benefits.
- **Other indicators (semi-quantitative only):** Implementation risk, Pollution impacts, Waste disposal impacts, Construction impacts, Operational impacts.

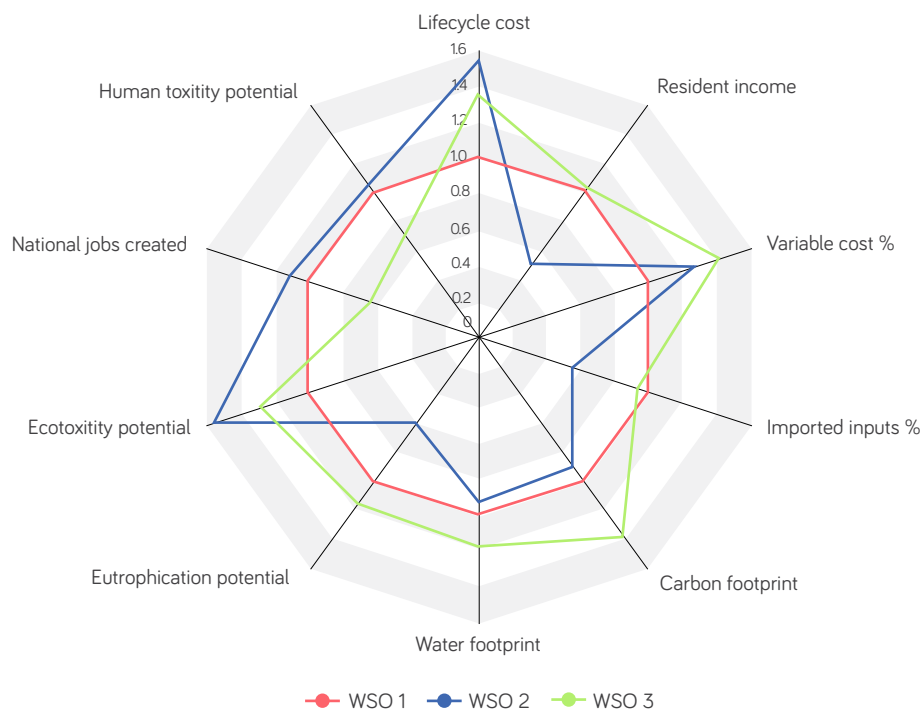


Figure 2: An example radar chart used to visualise and compare the unweighted triple bottom line results for each WSO. In this example, WSO1 (the base case), WSO2 (IPR) and WSO3 (DPR) (Stanford et al., 2018).

An example of one output provided by WaterSET is presented in Figure 2. The data in Figure 2 is an example only as one of the findings of WaterSET when used to evaluate three water supply options (WSOs), which were the “current status” involving pumping from a river system for treatment (WSO1), an indirect potable reuse scenario (WSO2) and a direct potable reuse scenario (WSO3). Local criteria could play a significant role in the findings. Hence it is not appropriate to define the exact water supply options used to generate the example data. This is a ‘radar chart’ in which the unweighted TBL results are shown for the three water supply options across the model’s quantitative criteria. Water supply options with a more favourable impact for a given criterion receive a higher score relative to the other water supply options.

If opted for by the user, all criteria values are then input into a MCDA, which involves the assignment of weights to each criterion and converting all criteria scores to a common measurement system that can be aggregated into a total score for each water supply option. The water supply options are ranked in terms of overall favourability, accounting for quantitative criteria scores calculated by the model, qualitative criteria scores input by the user, and criteria weightings input by the user.

The TBL framework developed in the WaterSET study provides a means for water utilities to evaluate water supply options and treatment approaches for a single water supply or across a suite of options. A key feature of the approach is that the MCDA has been decoupled from the outputs of the TBL model, which allows users to view the quantitative impacts of water supply options separately from the MCDA output. It also provides an opportunity for water utilities to determine if, and by how much, different weighting factors may impact the favourability of a specific water supply option or treatment approach.

The project report includes a number of case studies, including one undertaken for a medium-sized regional Australian water utility. The purpose of the case study was not to recommend investment in any of the modelled alternative water supply options, but rather to explore how available water supply options compare across the WaterSET criteria to gain a better overall understanding of the potential options.

3.2.3 Context-specific nature of water supply decisions

The drivers and incentives for potable reuse – as for any water supply option – will ultimately lie in how the various available water supply options compare against the key criteria. This is a highly geographically specific consideration and thus very different conclusions are expected to be drawn by different cities. Nonetheless, there is ample evidence to observe that some cities have identified potable reuse as an attractive water supply option, based on considerations of criteria including water supply availability, cost and energy consumption.

4

Guidelines and Best Practice

There are now numerous well-developed frameworks for managing risks from drinking water and recycled water. These include frameworks developed in Australia, the USA and by the World Health Organization (WHO).

Australian water quality guidelines developed since 2004 have exhibited a significant philosophical departure from the traditional focus on 'end point monitoring' as a means of water quality compliance. Instead, they have adopted a 'risk management' approach, also embodied in the WHO Guidelines for Drinking Water Quality and the Water Safety Plans described therein. This approach emphasises the assessment and management of possible means by which contaminants may be introduced to water, and preventative measures for minimising such contamination. With reduced emphasis on end-point monitoring, Australian regulations have focussed on implementation of risk management plans.

Australian and WHO guidelines for water recycling (including potable reuse) have adapted and built-upon these successful risk management frameworks. Water recycling guidelines have further progressed a number of additional concepts, such as the application of health-based targets for water quality, which are now being actively considered for adoption in future revisions of the Australian Drinking Water Guidelines (ADWG). Some key aspects of process validation and monitoring have also been further developed for water recycling and may be reflected in future drinking water guidance.

This chapter provides an overview of the philosophical basis, and some important elements, of key documents that provide guidance and best practice advice relevant to potable water reuse.

4.1 Australia

Relevant water quality guideline documents in Australia include the ADWG as well as the Phase 1 and Phase 2 Guidelines for Water Recycling. On a historical note, the AGWR were under development from 2004, but with an exclusive focus on non-potable applications (Phase 1). The need to extend these to address potable reuse was belatedly recognised during 2006 and the Phase 2 AGWR were then developed and published in 2008. To a large degree, these documents reference and support one another, thus a comprehensive understanding of the overall approach requires some discussion of each.

4.1.1 Australian Drinking Water Guidelines

The ADWG introduce a framework for management of drinking water quality (NHMRC & NRMMC 2011). A key component of the framework is system analysis and management, which involves understanding the entire water supply system, the hazards and events that can compromise drinking water quality, and the preventive measures and operational control necessary for ensuring safe and reliable drinking water.

The ADWG accept that realistic expectations for hazard identification and risk assessment are important and that rarely will enough knowledge be available to provide complete a detailed quantitative risk assessment. Instead, the guidelines have adopted a risk prioritisation process, adapting the risk matrix approach presented in the risk management guidelines published by Standards Australia & Standards New Zealand (2013). A likely outcome of such risk assessments is the identification of specific areas where further information and research is required.

Health-based guideline values are provided for many organic and inorganic chemicals. These represent concentrations that, based on present knowledge, do not result in any significant risk to the health of the consumer over a lifetime of consumption. Guideline values for chemical substances were derived using human data when available or, in most cases, by using animal data adjusted by appropriate safety factors for extrapolation to humans.

The ADWG explicitly recognise that pathogenic micro-organisms present the greatest threat to the safety of drinking water supplies. Current microbial water quality monitoring is focussed on *E. coli* as a faecal indicator organism. However, it is well established that some waterborne faecal pathogens are more resistant to some common drinking water disinfection processes (e.g., chlorination) than *E. coli*. Therefore, monitoring of *E. coli* serves as a useful verification of the disinfection process, but cannot be relied upon entirely.

Instead, water quality and safety is maintained by monitoring performance of identified 'critical control points' (CCPs), which are steps, processes or procedures that control significant hazards. A number of CCPs have been determined, based on their established relationship to effective pathogen control. CCPs can include a range of treatment (e.g., disinfection) and non-treatment (e.g., catchment management) barriers. In this context filtered water turbidity and applied disinfectant doses are recognised as indicators of microbiological quality. Continuous monitoring of CCPs is preferred where possible. This reliance upon CCPs is a departure from a traditional 'endpoint monitoring' approach to water quality management and represents a crucial component of the overall 'risk management' approach. This risk management approach is based on the Hazard Analysis and Critical Control

Points (HACCP) approach originally developed for risk management in the food supply chain. It is widely supported within the Australian water industry and by public health regulators.

Although the risk management approach for drinking water quality has been effective and is widely supported, there is a growing acceptance in the Australian water industry that further development of this approach is warranted in the near future. In particular, it has been recognised that specific maximum levels of ‘acceptable’ or ‘tolerable’ risk from pathogens must be identified and targeted for achievement by drinking water providers. As such, the water industry and its regulators are currently working towards the development of ‘health based targets’ for microbial water quality. Exactly how these health based targets will be applied is yet to be finalised, but it is likely that they will develop along the lines of the approach already taken in the Australian Guidelines for Water Recycling – Phase 1 (see Section 4.1.2).

4.1.2 Australian Guidelines for Water Recycling – Phase 1

Phase 1 of the *Australian Guidelines for Water Recycling* (AGWR) was published in 2006 by the Natural Resource Management Ministerial Council and the Environment Protection and Heritage Council (2006). An update of these Guidelines is expected to be released during 2019. Phase 1 did not cover the development or management of potable water recycling schemes. However, the guidance that it provides for managing risks associated with non-potable water reuse applications also underpins the Phase 2 Guidelines (see Section 4.1.3), for potable water recycling.

The AGWR are notable for the risk management framework that they provide, rather than simply relying on end-product (recycled water) quality testing as the basis for managing water recycling schemes. The risk management framework used is based on the framework detailed in the ADWG (see Section 4.1.1). However, an important further development is that the water recycling guidelines promote a quantitative assessment of health-based risks (with a strong focus on risks from pathogens).

In managing risks from pathogens to human health, the guidelines provide a numerical definition of safety. Specifically, they use disability adjusted life years (DALYs) to convert the likelihood of infection or illness into burdens of disease, setting a tolerable risk of 10^{-6} DALYs per person per year. The tolerable risk is then used to set health-based targets that, if met, will ensure that the risk remains below 10^{-6} DALYs per person per year.

DALYs for a disease or health condition are calculated as the sum of the years of life lost due to premature mortality in the population and the years impacted by disability for incident cases of the

health condition. One DALY can be thought of as one lost year of “healthy” life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability.

The concept then is that if source water quality is (approximately) known, and if risks of exposure can be properly characterised (using dose-response relationships and other factors such as existing immunity in the community), then it is possible to set ‘system performance targets’ based on reaching the ‘tolerable burden of disease’ (10^{-6} DALYs per person per year).

The practical application of this approach is focused on three carefully selected ‘reference pathogens’ representing enteric viruses (a combination of rotavirus and adenovirus), bacteria (*Campylobacter jejuni*) and protozoa (*Cryptosporidium parvum*). Assessment of raw water concentrations of these reference pathogens, and determination of the relationship between exposure and DALYs lost, enables the determination of overall treatment process performance to ensure that exposure in finished water is below the levels corresponding to 10^{-6} DALYs per person per year.

Among the advantages of the health-based targets approach are that water recycling schemes are afforded a high degree of flexibility in their design. The use of specific treatment technologies, or conditions such as minimal travel times in aquifers, is not stipulated. This accommodates future developments in technology and the consideration of unique characteristics of specific projects. Furthermore, it ensures that the key design feature of all schemes is explicitly identified as the satisfactory protection against public health risks.

To aid compliance with the AGWR, much recent research has been conducted on hazardous events in Australian water recycling systems, with a major focus having been on biological systems, including membrane bioreactors (Trinh *et al.*, 2014b). This research has produced new insights regarding the impacts of hazardous events on the treatment performance for bulk water quality parameters (Trinh *et al.*, 2014a), trace organic chemical contaminants (Trinh *et al.*, 2015) and microorganisms (Branch *et al.*, 2016). Requirements for enhanced performance monitoring of advanced water treatment processes has also produced innovative research, including the characterisation of reverse osmosis permeates using fluorescence spectroscopy (Singh *et al.*, 2012), the application of online fluorescence monitoring of reverse osmosis fouling and integrity (Singh *et al.*, 2015) and the development of a pressure decay test for reverse osmosis protozoa removal validation (Zhang *et al.*, 2016).

4.1.3 Australian Guidelines for Water Recycling – Phase 2

Phase 2 of the *Australian Guidelines for Water Recycling* consists of three modules that specifically address stormwater use (NRMMC, EPHC & NHMRC 2009b), managed aquifer recharge (NRMMC, EPHC & NHMRC 2009a), and augmentation of drinking water supplies (NRMMC, EPHC & NHMRC 2008). The module for the augmentation of drinking water supplies, in particular, provides risk management guidance for chemical and pathogenic contaminants in addition to that which was provided in the Phase 1 guidelines.

Consistent with the Phase 1 guidelines, the Phase 2 guidelines use DALYs as a measure of risk associated with pathogenic organisms and apply a tolerable risk of 10^{-6} DALYs per person per year. The approach uses the following reference pathogens: *Cryptosporidium* for protozoa and helminths, a rotavirus and adenovirus combination for enteric viruses, and *Campylobacter* for bacteria. The default 95th percentile values for these organisms, per litre of sewage, are given as 2000 *Cryptosporidium*, 8000 rotavirus and 7000 *Campylobacter*. Using these values, the level of treatment for pathogen reduction required to achieve compliance with 10^{-6} DALY per person per year can be calculated. The minimum log reduction values (LRVs) required for production of drinking water from sewage were thus determined to be:

- *Cryptosporidium*: 8 LRV
- Enteric viruses: 9.5 LRV
- *Campylobacter*: 8.1 LRV

A combination of treatment processes is then required to cumulatively achieve these levels of log reductions. In order to receive credit for them, individual schemes are required to validate the performance of treatment processes against the LRVs that they are said to achieve. As a rule, regulators will only credit treatment processes with the maximum LRVs that can be continuously and reliably monitored.

The AGWR Phase 2 stipulates that, “where chemicals are listed in the drinking water guidelines, it is appropriate to apply the same values to drinking water augmentation schemes.” Where chemicals are not dealt with in the ADWG, an approach is provided to set values based on tolerable risk. The approach adopted for chemicals is based on that of the ADWG where the tolerable risk is implemented through the development of corresponding guideline values. For chemicals with threshold toxicities, the guideline values generally correspond to identified No Observed Adverse Effect Levels (NOAELs) or Lowest Observed Adverse Effect Levels (LOAELs) with applied uncertainty factors. For non-threshold toxicity chemicals, such as carcinogens, guideline values are based on the 1×10^{-6} cancer risk following lifetime consumption (defined as 70 years).

Chemical guideline values are tabulated in the guidelines along with maximum concentrations of the chemicals that have been reported

from studies of secondary or tertiary treated wastewater. The data were compiled from a range of Australian and international datasets. However, the guidelines note that the table should not be taken as exhaustive and that detailed assessment of individual systems—including surveys of industrial, agricultural, domestic and urban inputs—should be undertaken to identify potential chemical hazards that could affect source water quality. In most cases, this assessment will need to be supported by extensive monitoring of the source water quality.

Guideline values for human pharmaceuticals were derived from lowest daily therapeutic doses divided by uncertainty factors of 1,000–10,000. Guidelines for pharmaceuticals used for agricultural or veterinary purposes were developed from acceptable daily intake (ADI) values established by a range of international food and health agencies.

Where neither existing guidelines, nor relevant toxicological data for developing guidelines was available, a quantitative structure–activity relationship approach was used as method for determining thresholds of toxicological concern (TTCs). The use of TTCs is well established internationally and has been applied by the United States Food and Drug Administration (FDA) and the WHO for setting guidelines for minor chemical contaminants (WHO 1987; FDA 2006). However, this approach is very conservative and not based directly on toxicity. This can sometimes result in values less than available analytical detection limits. If TTCs are used, they should be implemented with caution and an appreciation for the inherent conservativeness.

Both the Western Corridor Recycled Water Scheme in South East Queensland and the Groundwater Replenishment Scheme in Perth were developed and assessed under the framework of the AGWR (Radcliffe, 2015). Furthermore, there have been recent examples of Australian water utilities applying the concepts underpinning the AGWR to conventional water supplies as a means of identifying current performance deficiencies (Shea *et al.*, 2016). Similarly, the AGWR have been applied to a conceptual ‘re-validation’ of the long established Goreangab direct potable reuse plant in Windhoek, Namibia (Law *et al.*, 2015).

4.1.4 Validation of treatment processes for AGWR treatment performance

In the years following the release of the AGWR, it was widely observed that the requirements for ‘validation’ of the performance of some water recycling projects were arduous and in need for further guidance (Radcliffe, 2015). A significant body of research was carried out to address this knowledge gap, supported by funding from the Australian Water Recycling Centre of Excellence. Much of this work focused on the development and improvement of methods for integrity monitoring of key potable reuse treatment technologies, such as reverse osmosis (Pype *et al.*, 2016).

Important outcomes included the production of five new “validation protocols”, under the banner of WaterVal. These validation protocols provide detailed validation concepts and procedures for UV disinfection (WaterSecure, 2017e), chlorine disinfection (WaterSecure, 2017a), membrane bioreactor performance (WaterSecure, 2017b), ozone disinfection (WaterSecure, 2017c) and reverse osmosis and nanofiltration performance (WaterSecure, 2017d). These validation protocols are now managed by, and available by contacting, WaterRA. Further research developments, yet to be incorporated in formal validation protocols have included the application of Bayesian Networks as a framework for the validation of some key unit processes including biological wastewater treatment (Carvajal *et al*, 2015), ultrafiltration (Carvajal *et al*, 2017b), ozone disinfection (Carvajal *et al*, 2017a), and chlorine disinfection (Carvajal *et al*, 2017c).

4.2 The World Health Organization

In 2017, the World Health Organization published ‘Potable Reuse: Guidance for Producing Safe Drinking Water’ (WHO 2017). These WHO potable reuse guidelines state that the management of potable reuse schemes should be based on the WHO framework for safe drinking water, including water safety plans (WSPs). This is a reference to the framework presented in the WHO Guidelines for Drinking water Quality (WHO 2011), and the approach to WSPs described in Chapter 4 of that document. In making this statement, the WHO is indicating that the approach to the management of potable reuse projects is fundamentally consistent with the general approach to managing any other drinking water supply. The framework includes three components (WHO 2017):

- **Health-based targets:** These are risk-based measurable objectives that define the safety of drinking water. They include performance targets to achieve microbial safety and numerical water quality targets for chemical and radiological parameters.
- **Water safety plans:** A comprehensive risk assessment and risk management approach developed and implemented by water suppliers. A WSP includes:
 - **System assessment** to identify, assess and ensure management of public health risks along the water supply chain. Key activities include describing the water supply system; identifying hazards

and hazardous events and assessing the associated risks; determining and validating control measures, reassessing and prioritizing the risks; and developing, implementing and maintaining an improvement/upgrade plan.

- **Monitoring** to determine whether the control measures put in place are effective, that the WSP is being implemented in practice and that the system, as a whole, is effective and achieving health-based targets. Key activities include defining monitoring of the control measures and verifying the effectiveness of the WSP.
- **Management and communication** to ensure that appropriate operational and management systems are in place to support and sustain water safety. Key activities include preparing management procedures (including incident protocols) and developing supporting programmes.
- **Independent surveillance:** Activities undertaken by the regulatory agency to ensure that WSPs are being implemented effectively and that health-based targets are being met.

4.2.1 Water quality targets and microbial performance targets

The WHO Guidelines state that water quality targets (chemical guideline values) and microbial performance targets (log reductions of pathogens in source waters) are the primary health-based targets for potable reuse. These targets are underpinned by health outcome targets set by public health authorities or drinking water regulators. The reference level of risk of 10^{-6} disability-adjusted life years (DALYs) per person per year (pppy) included in the WHO Guidelines for Drinking water Quality is also adopted in the WHO potable reuse guidelines. However, they state that regulators may choose to adopt this as a target or alternatively can vary it depending on local circumstances, including overall burdens of disease (WHO 2017).

Microbial performance targets can be identified by using system specific pathogen data in source waters or by using default pathogen concentrations. Default performance targets identified in the guidance and corresponding LRVs to achieve 10^{-6} DALYS pppy are provided in [Table 1](#).

Table 1: Performance targets calculated from default concentrations of pathogens (WHO 2017).

	Pathogens		
	Enteric bacteria (<i>Campylobacter</i>)	Enteric viruses (noroviruses)	Enteric protozoa (<i>Cryptosporidium</i>)
Default concentration (per litre) in source wastewater	7000	20000	2700
Log reductions (rounded to nearest 0.5 Log)	8.5	9.5	8.5

The WHO potable reuse guidelines do not provide any new guideline concentrations for chemical contaminants, beyond what are already provided in the WHO Guidelines for Drinking water Quality. This is based on the fact that chemicals of emerging concern, such as pharmaceuticals and personal care products, tend to be present at concentrations, which are generally low and generally do not warrant setting of new guideline values.

However, in specific circumstances, where a chemical with no guideline value is identified as a concern, approaches for developing screening values are identified to support investigations into potential risks and the need for implementation of additional control measures. The principal reference is to the framework presented in the AGWR (NRMCC, EPHC & NHMRC 2008).

4.2.2 Application of water safety plans to potable reuse

While WSPs are said to apply equally well to all types of drinking water supplies, there are specific characteristics of potable reuse schemes that need to be considered as part of system assessment (WHO 2017). These include the high concentrations of microbial pathogens in wastewater and potential presence of a wide range of industrial, commercial and domestic chemicals.

The approach adopted for addressing the high concentrations of microbial pathogens and chemical contaminants is based on the adoption of “control measures”. This term used to describe measures taken to reduce or manage exposure to people by hazards including pathogens and chemicals. They most obviously include various water treatment processes, but also include other measures such as source control:

“Control measures should be applied from collection of wastewater to delivery of drinking water to consumers. Control measures at the source include requirements on industrial discharge quality and changing wastewater collection areas to reduce or eliminate industrial discharges” (WHO 2017).

4.2.3 Validation of control measures

The Guidelines state that potable reuse generally requires complex treatment trains with high levels of reliability; and furthermore that control measures need to be validated:

“Control measures used in potable reuse schemes need to be validated to demonstrate that individual processes will meet performance targets and collectively, will consistently and reliably produce safe drinking water and ensure that public health is protected. Although this is no different from other sources of drinking water, the broader range of chemical contaminants and relatively high concentrations of microbial pathogens in untreated wastewater can increase the focus on validating performance” (WHO 2017).

The first component of validation is demonstrating the removal of chemical or microbial hazards by control measures, which is usually performed using challenge tests. The most direct approach is to measure \log_{10} reduction values (LRVs) of reference pathogens achieved by treatment processes. A summary of validated LRVs demonstrated by challenge testing (LRV_{c-test}) for a range of indicative treatment processes commonly used in potable reuse projects is presented in the Guidelines and reproduced here in [Table 2](#).

The second component of validation is identifying operational criteria that can be used to demonstrate ongoing performance of control measures. Operational monitoring parameters are required to ensure that any deviation from required performance is detected in a timely fashion. For some treatment processes, testing of operational parameters used to monitor them typically lacks the sensitivity of tests for pathogen removal. For example, membrane filtration processes can be shown to achieve pathogen LRVs of 6 or more in challenge testing but turbidity removal is limited to a sensitivity of 1.5–2.0 logs (WHO 2017). Since the monitoring sensitivity is often the limiting factor for ongoing treatment performance assessment, the LRVs attributed to these treatment processes are most commonly based on the operation monitoring sensitivity (LRV_{OMS}). Validated LRV_{OMS} values are also summarised in the Guidelines and reproduced here in [Table 2](#).

Table 2: Validated log reduction values based on challenge testing and operational monitoring sensitivity (LRV_{C-test} and LRV_{OMS}) for indicative treatment processes^a (WHO 2017).

Treatment Process	LRV _{C-test} ^b			LRV _{OMS} ^b		
	Bacteria	Virus	Protozoa	Bacteria	Virus	Protozoa ^c
Secondary wastewater treatment (without disinfection)	3	2.5	2	1	0.5	0.5
Soil-aquifer treatment	6	6	6	System specific		
Membrane bioreactor	5	5	6	4	1.5	2
Microfiltration or ultrafiltration	6	4-6	6	4	0 ^d	4
Ozone-biological activated carbon	6	6	3	4	4	0
Reverse osmosis	6	6	6	1.5-2 (online conductivity or TOC monitoring) 2.5-4 (Off-line sulfate or on/off-line fluorescent dye monitoring)		
Ultraviolet light disinfection	6	6	6	6	6	6
Ultraviolet light/advanced oxidation process	6	6	6	6	6	6
Chlorination	6	6	0	6	6	0
Drinking water treatment plant (coagulation, flocculation, filtration, chlorination)	6	6	3-4	6	6	3-4

^a Generally LRV_{OMS} based on challenge testing and sensitivities of operational monitoring should be used, particularly where operational monitoring is relied upon for demonstrating ongoing performance of treatment processes. However, proponents, in consultation with regulators, can choose whether LRV_{C-tests}, which are based only on challenge testing, can be used.

^b Challenge testing performed in laboratory testing or field trials. Upper LRV of 6 used. In the case of disinfectants this is typically an extrapolation of observed results.

^c Protozoa LRVs based on *Cryptosporidium*.

^d LRVs for viruses can be validated on a case-by-case basis.

Regarding the use of values in Table 2, the WHO Guidelines state:

“Generally, the LRV_{OMS} should be adopted in designing potable reuse schemes. This is consistent with the reliance in WSPs on the use of operational monitoring to demonstrate ongoing performance of control measures. However, proponents of potable reuse schemes, in consultation with regulators and other stakeholders, can choose whether validated LRVs based on results from challenge testing are used with or without considering the sensitivity of operational monitoring (i.e. LRV_{C-test} or LRV_{OMS})” (WHO 2017).

In the case of chemical hazards, removal can be linked to operational monitoring of selected surrogates and indicators. For example, Total Organic Carbon (TOC) can be used as an operational parameter to monitor general removal of chemical

hazards by RO. Discrete chemical species that may or may not be of direct public health relevance can also be used as operational indicators of treatment performance. An example is given for the artificial sweetener sucralose, which can be applied as an indicator of treatment process efficacy since it is relatively resilient to oxidation and biological processes, yet is well removed by RO.

A practical example of the use of a limited set of chemical parameters is provided in a case study for the Groundwater Replenishment Scheme in Perth (see Section 10.10 for a description of this project). In this case, a suite of 15 chemicals representing DBPs, inorganic and organic chemicals, pharmaceuticals, hormones, pesticides and phenols were used to assess treatment performance (Table 3). These parameters are monitored at a higher frequency than those included in verification monitoring.

Table 3: Indicator chemicals used for the Beenyup potable reuse scheme, Perth, Australia (WHO 2017).

Indicator parameters	Guideline value	Unit	Chemical group represented
Boron	4	mg/L	Inorganic chemicals
N-Nitrosodimethylamine	100	ng/L	Nitrosamines
Nitrate as nitrogen	11	mg/L	Inorganic chemicals
Chlorate	0.7	mg/L	Inorganic DBPs
1,4-Dioxane	50	µg/L	Organic chemicals
Chloroform	200	µg/L	Other DBPs
Fluorene	140	µg/L	Organic chemicals
1,4-Dichlorobenzene	40	µg/L	Organic chemicals
2,4,6-Trichlorophenol (use ceased)	20	µg/L	Phenols
Carbamazepine	100	µg/L	Pharmaceuticals and personal care products
Estrone	30	ng/L	Hormones
Ethylenediaminetetraacetic acid	250	g/L	Organic chemicals
Trifluralin	50000	ng/L	Pesticides and herbicides
Diclofenac	1.8	µg/L	Pharmaceuticals and personal care products
Octadioxin	9000	pg/L	Organic chemicals

4.2.4 Bioassays for direct toxicity testing

During the last decade, a considerable body of work has been undertaken in developing a series of ‘bioassays’, which may potentially be deployed for direct toxicity testing of water samples (Jia *et al.*, 2015; Leusch & Snyder, 2015). Driving this development has been a number of proposed benefits, including the possibility that low levels of toxicity (towards a variety of human health and ecotoxicity endpoints) may be detected, even when the identity of chemicals imparting the toxicity is unknown (Leusch *et al.*, 2014a). Other possible benefits may include improved detection sensitivity, compared to direct chemical analysis (Leusch *et al.*, 2014b; Mehinto *et al.*, 2015). Furthermore, direct toxicity testing may provide a possible means to account for unanticipated ‘mixture impacts’, whereby a mixture of chemicals may produce an overall toxicity that differs from a simple sum of its contributing parts.

The WHO Guidelines do not promote the application of bioassays for direct toxicity testing of water produced by potable reuse treatment technologies. However, an information text box is devoted to discussing this “potential use of bioanalytical tools”. This states (in part):

“There is still significant uncertainty regarding the potential role of bioanalytical tools in a regulatory context. In vitro bioassays measure the initial interaction of the xenobiotic at the molecular or cellular site, and generally do not take into account toxicokinetic modulators of toxicity (absorption, distribution, metabolism and excretion). In addition, defence and repair mechanisms can compensate for toxic injury in whole organisms. Therefore, it is difficult to relate in vitro responses to adverse human health effects” (WHO 2017).

The text box concludes with:

“Further work is continuing on bioanalytical tools and if successful, it should provide greater public confidence in the capability of potable reuse schemes to produce safe drinking water. Developments in bioanalytical science should be monitored to identify useful candidate assays as they are validated” (WHO 2017).

4.3 The USA

The US EPA published the most recent update to US Guidelines for Water Reuse in 2012 (US EPA 2012). These Guidelines are not specifically focused on potable reuse, and most of their content addresses non-potable reuse applications. The key section which does address potable reuse is very clear about the significance of unplanned potable reuse, for which the Guidelines have adopted the term ‘*de facto*’ potable reuse:

“The use of reclaimed water to augment potable water supplies has significant potential for helping to meet future needs, but planned potable water reuse only accounts for a small fraction of the volume of water currently being reused. However, if de facto (or unplanned) water reuse is considered, potable reuse is certainly significant to the nation’s current water supply portfolio. The unplanned reuse of wastewater effluent as a water supply is common, with some drinking water treatment plants using waters from which a large fraction originated as wastewater effluent from upstream communities, especially under low-flow conditions. Thus, the term de facto reuse will be used to describe unplanned IPR, which has been identified in the NRC report (2012), and is becoming recognized by professionals and the general public.

Examples of *de facto* potable reuse abound, including such large cities as Philadelphia, Nashville, Cincinnati, and New Orleans, which draw their drinking water from the Delaware, Cumberland, Ohio, and Mississippi Rivers, respectively. These communities, and most others using unplanned IPR sources, do provide their customers with potable water from these rivers that meet current drinking water regulations by virtue of the drinking water treatment technologies used².

Even more significant than the acknowledgement of the importance of *de facto* potable reuse, this edition of the Guidelines represents the first time that direct potable reuse has been highlighted as a potentially important water management strategy in the USA:

"In many parts of the world, DPR may be the most economical and reliable method of meeting future water supply needs. While DPR is still an emerging practice, it should be evaluated in water management planning, particularly for alternative solutions to meet urban water supply requirements that are energy intensive and ecologically unfavourable. This is consistent with the established engineering practice of selecting the highest quality source water available for drinking water production. Specific examples of energy-intensive or ecologically-challenging projects include interbasin water transfer systems, which can limit availability of local water sources for food production, and source area ecosystems, which are often impacted by reduced stream flow and downstream water rights holders who could exercise legal recourse to regain lost water². In some circumstances, in addition to the high energy cost related to long-distance transmission of water, long transmission systems could be subject to damage from earthquakes, floods, and other natural and human-made disasters. Desalination is another practice for which DPR could serve as an alternative, because energy requirements are comparatively large, and brine disposal is a serious environmental issue. By comparison, DPR using similar technology will have relatively modest energy requirements and provide a stable local source of water. It is important to note, however, that DPR will not be a stand-alone water supply. Therefore, in managing water supplies, other local sources will need to be combined with DPR to create reliable, robust, sustainable water supplies".

The Guidelines state that while the technical issues of DPR can be easily addressed through advanced treatment, there remains a significant task of developing public education and outreach programs to achieve public acceptance of this practice.

The US EPA Water Reuse Guidelines provide a useful overview of the types of projects (including potable reuse) that are possible, as well as some of the key obstacles which need to be addressed for various types of projects. However, they differ from the Australian and WHO Guidelines by largely avoiding any detailed descriptions of formalised risk management frameworks. The separation of responsibilities in the USA has left this level of detail to the responsibility of the state regulatory programs.

A summary of state regulatory programs for water reuse is provided in Chapter 4 of the Guidelines. Within that chapter, some suggested regulatory guidelines are provided and are intended to apply to reclamation and reuse facilities in the United States. It is stated that these guidelines are not intended to be used as definitive water reclamation and reuse criteria. They are intended to provide reasonable guidance for water reuse opportunities, particularly in states that have not developed their own criteria or guidelines.

The suggested guidelines for water reuse are provided for three approaches to potable reuse:

- Groundwater Recharge by Spreading into Potable Aquifers
- Groundwater Recharge by Injection into Potable Aquifers
- Augmentation of Surface Water Supply Reservoirs.

In each case, basic treatment requirements are stated, along with a description of the required recycled water quality, monitoring practices and "setback distances" (e.g., distance to nearest potable water extraction well, or distance required to provide two months retention time in a raw water supply reservoir). Although the proposed recycled water quality and monitoring requirements are predicated with the catch-all "includes, but not limited to", the focus is on conventional water quality parameters such as total coliforms, TOC and turbidity. There is no clear suggestion that monitoring may be focused on a critical control point approach to confirm treatment veracity.

While these Guidelines serve as a starting point, applied regulatory approaches vary significantly between the states. Two important examples (California and Texas) are discussed in Section 5.1 of this report.

² Note that this statement is specific to the legal context of the USA and should not be assumed to apply in other jurisdictions.

5

Regulatory Agency Approach to Potable Reuse

The Guideline documents presented in Chapter 4 outline broadly agreed approaches for the safe design, operation and management of potable water reuse projects. In many instances, they represent a coming together of multiple jurisdictions (such as the Australian states) with the aim of developing a cooperative and consistent approach. In all cases, regulatory agencies have played key roles in formulating appropriate water quality and safety objectives. As such, these Guideline documents provide a reliable indication of the general philosophy that will underpin the design and approval of most potable water reuse projects within the applicable jurisdictions.

However, the Guideline documents are not themselves legislated regulations. Thus it remains the responsibility of drinking water regulators to develop and impose criteria and other requirements to ensure the safe operation of potable reuse projects. This chapter presents some key insights to the approaches taken by some United States and Australian state-based regulatory agencies.

5.1 United States regulatory agencies

The *Safe Drinking Water Act (USA)* is the federal law that protects public drinking water supplies throughout the USA. It authorises the US Environmental Protection Agency (EPA) to establish minimum standards to protect drinking water and requires all owners or operators of public water systems to comply with these primary (health-related) standards.

State governments can be approved to implement these rules for EPA, and do so through detailed State Regulatory Codes. State-based regulators refer to these Regulatory Codes for the management of drinking water systems. Examples of the Codes, from California and Texas, are described in the following sections of this chapter.

5.1.1 California's Title 22 Code of Regulations

Regulation of potable reuse in California is governed by the Title 22 Code of Regulations, in which Chapter 3 of Division 4 addresses "Water Recycling Criteria" (California Office of Administrative Law, 2019). These regulations currently discriminate between three distinct approaches to potable reuse:

- Indirect Potable Reuse: Groundwater Replenishment - Surface Application
- Indirect Potable Reuse: Groundwater Replenishment - Subsurface Application
- Indirect Potable Reuse: Surface Water Augmentation.

The requirements in each case are detailed, but some important features are highlighted here. Pathogen reduction performance requirements have been developed based on the achievement of a 10^{-4} (i.e. 1 in 10,000) annual per capita risk of infection. For groundwater replenishment systems (either by surface or subsurface application), water treatment processes must be applied to filtered, disinfected municipal wastewater to achieve at least the following log reduction values:

- Enteric viruses: 12 LRV
- *Giardia* cysts: 10 LRV
- *Cryptosporidium* oocysts: 10 LRV.

In addition to these requirements, the treatment train must consist of at least three separate processes, each contributing at least 1 LRV. Furthermore, each engineered process may be credited with a maximum of 6 LRV. The achievement of these LRVs must be validated, either by approval of an existing validation report (e.g., from an equipment supplier) or by demonstrated challenge testing.

For each month retained underground, the recharged water may be credited with 1 LRV for viruses. In the case of surface application (but apparently not for subsurface application), demonstration of at least six months underground retention may also be credited with 10 LRV for each of *Giardia* and *Cryptosporidium*. With the exception of retention time underground, project proponents must develop a plan for on-going monitoring using the pathogenic microorganism of concern or a microbial, chemical, or physical surrogate parameter that verifies the performance of each treatment process's ability to achieve its credited LRV.

The more recently developed regulations for surface water augmentation are somewhat more prescriptive in terms of requirements for advanced water treatment processes. The use of "full advanced treatment" is stipulated, which is defined to include reverse osmosis and an oxidation treatment process. Minimum treatment performance and basic operational requirements (influent quality, transmembrane pressure, recovery, etc.) for each of these processes are also stipulated. A provision is made for the use of alternative treatment processes, but only in cases where it can be satisfactorily demonstrated that the proposed alternative provides an equivalent or better level of performance with respect to the efficacy and reliability of the removal of contaminants.

For the reverse osmosis treatment process, at least one form of continuous monitoring (e.g., conductivity, TOC, etc.), must be undertaken to indicate when the integrity has been compromised. For the oxidation treatment process, the proponent must demonstrate that the process will provide at least 0.5 LRV for the chemical 1,4-dioxane. Furthermore, a surrogate or operational parameter must be identified, which is capable of being monitored continuously to indicate when this performance is not being achieved.

The pathogen reduction requirements for surface water augmentation are dependent upon the relative proportion of dilution that will be achieved by augmentation of the surface water reservoir as shown in Table 4. Each separate treatment process may be credited with a maximum of 6 LRV for each pathogen, and at least two processes must be each credited with at least 1 LRV for each pathogen. The achievement of these LRVs must be validated, either by approval of an existing validation report or by demonstrated challenge testing.

Table 4: Pathogen reduction requirements prior to surface water augmentation (California Office of Administrative Law, 2019).

	Proportion of recycled water delivered to surface water reservoir during any 24-hour period	
	1% by volume	10% by volume
Enteric virus	8 LRV	9 LRV
<i>Giardia</i> cyst	7 LRV	8 LRV
<i>Cryptosporidium</i> oocyst	8 LRV	9 LRV

A surface water reservoir must have a minimum theoretical retention time of no less than that which has been approved by the Californian State Water Resources Control Board. The initial approved minimum theoretical retention time is set to 180 days. It is indicated that proposed alternative minimum theoretical retention times less than 120 days will require at least one additional LRV for each of enteric virus, *Giardia* cysts, and *Cryptosporidium* oocysts to be achieved prior to augmentation.

Unlike the pathogen reduction credits applied for subsurface residence time in groundwater replenishment projects, no pathogen reduction credits are provided for environmental residence time for reservoir augmentation projects (other than those implied by the dilution requirements). Consequently, all pathogen LRV requirements must be achieved by engineered treatment processes prior to augmentation.

The requirements for monitoring chemical contaminants are mostly consistent between the three identified approaches to potable reuse. They are, in general, much less onerous than the requirements for pathogen performance monitoring. Under normal circumstances, chemical contaminants monitoring is only required on a quarterly basis (grab or 24-hour composites) and is focused on treated water, prior to groundwater recharge or surface water augmentation. These quarterly samples must be tested for a wide range of contaminants and shown to comply with established maximum contaminant levels (MCLs) for drinking water quality.

Exceedances must generally be investigated with additional sampling and, if unresolved by additional sampling, a plan for corrective actions must be developed.

Note that in 2017, a Californian Assembly Bill (AB 574, as discussed in Section 5.1.2) repealed the definition of “Surface Water Augmentation” and established a new definition for “Reservoir Water Augmentation” in its place (State of California, 2017). It is expected that this change in terminology will flow through to the Title 22 regulations in time.

5.1.2 Proposed framework for regulating direct potable reuse in California

As described in Section 2.5, the State of California has been formally planning for DPR since at least 2010. In that year, the Governor of California signed into law Senate Bill 918, amending the California Water Code to require the California Department of Public Health to investigate the feasibility of developing regulatory criteria for DPR. From that requirement, a report was produced with the finding that the development of uniform criteria for DPR in California is feasible, and that those criteria could incorporate a level of public health protection as good as or better than what is currently provided by conventional drinking water supplies and IPR (California State Water Resources Control Board, 2016).

In 2017, a Californian Assembly Bill (AB 574) introduced new terminology and statutory definitions for two approaches to DPR. The Bill states that DPR includes, but is not limited to the following:

1. **“Raw water augmentation”**, which means planned placement of recycled water into a system of pipelines or aqueducts that deliver raw water to a drinking water treatment plant that provides water to a public water supply system, as defined in [Californian regulation].
2. **“Treated drinking water augmentation”** means the planned placement of recycled water into the distribution system of a public water system, as defined in [Californian regulation].

This Bill also requires the Californian State Water Resources Control Board to adopt uniform water recycling criteria for DPR through raw water augmentation before the end of 2023 (extendable by up to 18 months). To do this, the State Board must establish an expert review panel and the expert review panel must find that the proposed criteria would adequately protect public health, before any such criteria may be adopted. Furthermore, the Bill states that the State Board should establish a framework for the regulation of potable reuse projects by June, 2018. The Californian State Board met this deadline and produced a proposed framework for regulating DPR in California (California

State Water Resources Control Board, 2018). This proposed framework provided some additional clarification of the term “raw water augmentation” to mean projects where:

- The drinking water treatment plant is a filtration facility that has reliably demonstrated that it meets the requirements of California’s Surface Water Treatment Rule over a period of time;
- The recycled water is mixed with raw water in the conveyance to a drinking water treatment plant such that the blend provides a meaningful public health benefit; and,
- The project does not meet the requirements of the Surface Water Augmentation (and future Reservoir Water Augmentation) criteria.

Thus the water recycling criteria for DPR currently being developed in California will effectively mandate requirements for blending and subsequent treatment through a conventional drinking water treatment plant. There is no clear activity relating to the similar development of water recycling criteria for DPR through treated drinking water augmentation.

The proposed framework establishes that a risk management approach for pathogens and chemicals should be adopted for various types of potable reuse in the uniform recycling criteria.

The approach used to manage risks associated with pathogens is to identify a set of reference pathogens, identify the LRVs necessary to meet the health objective for each, and validate treatment processes for treatment trains that achieve the LRVs with the required reliability. While enteric virus, *Giardia* and *Cryptosporidium* were used to regulate IPR projects, it is indicated that additional and/or alternative pathogens are likely to be considered for DPR. Further reference is made to the current approach for regulating IPR projects in stating that “the loss of the benefits of the environmental buffer must be offset with equally effective and reliable engineered treatment proximate to the drinking water user”.

The proposed framework states that there are a number of instruments (e.g. engineered treatment reliability and redundancy, monitoring, system controls, LRV specifications) that can be required in a manner that compensates for the diminishing role of the environmental buffer. However, because no individual instrument is proved to be absolutely effective, several will be used in combination to address the risks.

Rather than allow the water microbial quality and risk of infection fluctuate significantly and meet the risk objective on an annual average, the treatment scheme for DPR is expected to be regulated to provide consistently safe water by imposing a daily risk of infection objective that would not exceed 2.7×10^{-7} per day (10^{-4}

per year/365 days per year = 2.7×10^{-7} per day). To minimise the chance that the LRVs necessary to meet this health objective are not consistently met, DPR projects must provide pathogen reduction capacity in excess of the basic LRVs. Determination of the required “redundant LRV treatment” will involve:

- Identifying an acceptable probability for failing to meet the LRV targets;
- Using probabilistic analysis of treatment train performance to evaluate the ability of candidate treatment trains to achieve the probability; and,
- Identifying the extra LRV capacity provided by treatment trains achieving the probability.

The proposed framework emphasises the need for monitoring to produce accurate real-time information for DPR control. It also states that a CCP program, where a treatment process loses LRV credit when monitoring no longer indicates effective treatment, is likely to be a requirement for DPR. It subsequently states that an effective CCP program is “essential” to the implementation of a fail-safe DPR project.

The approach used to control risks associated with chemical contaminants may be summarised as follows:

1. Identify treatment mechanisms that are effective for the control of broad categories of chemicals.
2. Identify treatment surrogates and conduct monitoring of surrogates and a suite of regulated and unregulated health-based and performance-based chemical indicators.
3. Conduct validation testing of treatment technologies.
4. Specify performance criteria to ensure effective treatment to reduce concentrations below the level of health concern.

This approach is coupled with regulatory requirements for industrial source control programs to help reduce the discharge of toxic chemicals to sewage, and other requirements that evaluate and reduce the risk of treatment failure. It is proposed that for DPR, source control requirements will likely be more stringent than current requirements applicable to existing IPR projects. Furthermore, it is suggested that a new group of chemicals will be addressed “due to their ability to persist through RO/AOP treatment and their potential public health impact (e.g. high concentration, short-term exposures)”.

The proposed framework states that for DPR, the minimum treatment requirements will be no less than those required for IPR (which, in some cases, specify reverse osmosis and an oxidative process). They also state that additional treatment and water quality monitoring will be required to ensure reliability, redundancy, robustness and process diversity (e.g. ozone-BAC).

The need for Operator Certification is also highlighted in the proposed framework. The California Water Environment Association and the California-Nevada American Water Works Association are jointly developing a certification program for operators specialising in potable reuse. It is stated that an advanced water treatment certification program should be available by the time DPR regulations are adopted. At the time of writing this report, the regulations for potable reuse in California remain in the proposed state and are yet to be finalised.

5.1.3 Texas Commission on Environmental Quality (TCEQ)

In recent years, many direct potable reuse projects have been initiated or established in the US state of Texas. These include the Raw Water Production Facility at Big Spring (see Section 10.12) and a temporary DPR configuration of a potable reuse project in Wichita Falls. Both projects were planned and implemented in the absence of any national or Texas-based guidance or regulatory resources specially addressing issues associated with DPR.

Regulatory approval for drinking water systems in Texas comes under the authority of the Texas Commission on Environmental Quality (TCEQ). The TCEQ manages compliance with public drinking water regulations provided in Title 30 of the Texas Administrative Code (State of Texas, 2017). This document provides comprehensive requirements for all public drinking water systems, but generally does not include many of the concepts that were developed specifically for the regulation of potable reuse projects in California. For example, the regulation of microbial contaminants is focused largely on the monitoring of *E. coli* as an indicator organism, rather than on the effective achievement of designated LRVs for viruses or protozoa.

The approach currently adopted by the TCEQ is that all drinking water facilities have their engineering design reviewed by the TCEQ to ensure they meet the minimum standards provided in Title 30 of the Texas Administrative Code. A TCEQ spokesperson justified this approach, stating that “the use of innovative technology to treat a nonstandard source water must be reviewed on a case-by-case basis, and must show that the design and operation of the facility will produce water that meets the federal and state water-quality regulations” (Associated Press, 2016).

In order to provide some more specific technical guidance, the Texas Water Development Board (TWDB) sponsored production of the TWDB “Direct Potable Reuse Resource Document” (TWDB 2015). The document is intended to be a technical resource for utilities, consultants, planners, academics, and other parties interested in evaluating the feasibility of implementing DPR or for utilities that have determined that DPR is feasible and are entering the planning phase of a project. The Introduction chapter makes it clear that while

technical staff from TCEQ participated in the project and provided feedback on its content, it is not a regulatory document. A strong recommendation is provided that any public water system interested in pursuing DPR meet with the TCEQ Water Supply Division and Water Quality Division early in the pre-planning phase of the project to ensure that regulatory requirements will be adequately addressed.

The Direct Potable Reuse Resource Document states that because a DPR project will require advanced treatment, the conventional water treatment provisions of the Texas Administrative Code are not sufficient. TCEQ must evaluate each DPR project on a case-by-case basis, and evaluate the types of treatment technology needed to ensure there are no “adverse effects” pursuant to the Code (TWDB 2015).

Although there are no additional adopted regulations regarding the process for review for a DPR project, the TCEQ is reported to have “a fairly extensive set” of documents, including final approval letters for at least three DPR projects (Colorado River Municipal Water District Project at Big Spring, the City of Wichita Falls Project, and the proposed City of Brownwood Project) (TWDB 2015). These final approval letters can be used as some form of guidance as to how TCEQ implements the Texas Administrative Code for DPR projects. It is stated that these letters can be obtained from the TCEQ through the public information request process.

Elsewhere in the Direct Potable Reuse Resource Document, it is stated that the TCEQ has established minimum (or baseline) log removal and/or inactivation targets for viruses and protozoa (TWDB 2015). These TCEQ baseline targets are based on the 10^{-4} infection risk level and established drinking water treatment performances. Following conventional wastewater treatment, the baseline pathogen log reduction targets are for *Cryptosporidium* (5.5 LRV), *Giardia* (6 LRV) and virus (8 LRV). The baseline log removal targets are considered a starting point for the TCEQ approval process and may be revised upward based on data collected from the wastewater in question.

A second important technical document sponsored by the Texas Water Development Board provides guidance on monitoring for DPR projects (Steinle-Darling *et al.*, 2016). This document canvasses many approaches to monitoring, including monitoring of chemical and microbial contaminants, the use of indicator chemicals and microorganisms, bioassays for toxicity testing and critical control point-based monitoring. A useful table is provided (Table 5.2 in that document) summarising the recommended monitoring methods for DPR projects. “Standard methods” are presented as methods in place at most advanced treatment facilities. The table also includes proposed and recommended monitoring methods that are not yet routinely included in potable reuse projects, and may be at varying stages of development or validation.

5.2 Australian regulatory agencies

While there had been many small potable reuse projects proposed during earlier decades, sudden major interest in potable reuse during the millennium drought (peaking 2006–2008) prompted a renewed focus by Australian regulators. Partially in response to the National Water Initiative (COAG 2004), Australian Guidelines for Water Recycling (AGWR) were under development, but with an exclusive focus on non-potable applications. The need to extend these to address potable reuse was belatedly recognised during 2006 and the Phase 2 AGWR guidelines were subsequently published in 2008 (NRMCC, EPHC & NHMRC 2008).

By the time the Phase 2 AGWR were available, one of the key projects that had necessitated their development, in Toowoomba, Queensland had already been abandoned due to lack of community support. Furthermore, much more significant plans, for what would become the Western Corridor Water Recycling Scheme had been announced by the Queensland Premier, Peter Beattie. This situation left Queensland regulators in the unenviable position of having to develop regulatory requirements for this major project at the same time as the relevant national guidelines were being developed. Plans for Perth's Groundwater Replenishment Scheme were also developing, but this project was to be preceded by a much smaller trial scheme (during 2010–2012), thus any urgency for clear national regulatory guidance was less apparent.

In addition to reviewing current legislation with an aim of reducing inconsistencies, it would be valuable in the context of potable reuse, to consider a detailed review of drinking water and recycled water legislation across all states with an aim of ensuring that legislation everywhere supports the efficient and consistent supply of safe water, regardless of the source.

In the future, it may be possible that the Commonwealth could provide national legislation on water quality standards. However, such action would need to be in compliance with Section 100 of the Australian Constitution, which disallows the Commonwealth to “abridge the right of a State or of the residents therein to the reasonable use of the waters of rivers for conservation or irrigation”. An outcome of Section 100 has meant that most responsibilities for managing water in Australia have remained with the State/Territory governments. In practice, any legislative role for the Commonwealth tends to require support from an intergovernmental agreement between the Commonwealth and the States/Territories, as was the case for the National Water Initiative and the Murray Darling Basin Plan.

5.2.1 Queensland

The principle legal requirements for ensuring drinking water safety in Queensland are set out in the *Water Supply (Safety and Reliability) Act 2008* (State of Queensland, 2017). Within the requirements of this Act, registered drinking water service providers are required to hold an approved drinking water quality management plan in order to carry out a drinking water service. The purpose of a drinking water quality management plan is to protect public health.

Each drinking water service provider must prepare a drinking water quality management plan for the provider's drinking water service and apply to the regulator for approval of the plan. This plan is largely a risk management plan with the service provider expected to identify such things as “hazards and hazardous events” that may affect drinking water quality, an assessment of the risks posed and a demonstration of how those risks will be managed. Requirements are also included for regular review and auditing of water quality management plans.

The *Water Supply (Safety and Reliability) Act* (QLD) includes an additional chapter addressing Recycled Water Management. While this chapter applies to various forms of water recycling (e.g., for non-potable uses), recycled water “supplied to augment a supply of drinking water” is specifically mentioned. For this application and some others, an approved “recycled water management plan” is required. Similar to a drinking water quality management plan, this plan is largely a risk management plan with requirements for assessing risks and outlining how they will be managed. Requirements are also included for regular review and auditing.

If the recycled water is proposed to be supplied to augment a supply of drinking water, an approved validation program for the scheme is also required. The regulator may select and impose available guidelines for such validation programs. Therefore, no technical details are provided in the Act regarding applicable validation programs.

In the case of indirect potable reuse, where the recycled water is to be used to augment a potable water supply, a regulator must not approve the recycled water management plan for the recycled water scheme unless there is an approved drinking water quality management plan for the water storage.

In the case of both drinking water quality management plans and recycled water quality management plans, references are made to requirements to comply with “water quality criteria”. Definitions are provided for water quality criteria in relation to each of drinking water and recycled water. In both cases, they include (but are not limited to) standards prescribed in a regulation under the *Public Health Act, 2005* (QLD).

Quality standards for drinking water, and for recycled water intended to augment a supply of drinking water, are stipulated in the Queensland Public Health Regulation (State of Queensland, 2018). Both types of quality standards are applicable to potable reuse. The quality standards for recycled water (Section 53) apply to the recycled water, following treatment, but prior to “augmentation”, whereas the quality standards for drinking water (Section 52) apply to the final drinking water, which may have been produced partially by augmentation.

The Regulation as applied to drinking water makes reference to the ADWG, and particularly to the monitorable water quality parameters listed as guidance in that document. Microbial water quality monitoring requirements are focused on monitoring *E. coli* in finished water. For chemical contaminants, it is stated that “each sample of drinking water must not contain an amount of an ADWG parameter more than the guideline value for health for the parameter stated in the physical and chemical guideline table”. This is presumably a reference to Table 10.5 in Chapter 10 of the ADWG.

The quality standards for recycled water intended to augment a supply of drinking water are notably more onerous. In addition to requirements to comply with the ADWG parameters (as for drinking water), there are requirements relating to microorganisms and chemical parameters presented in “Schedule 6” of the Regulation. Schedule 6 lays out water quality standards for four microbial parameters (*Clostridium perfringens* spores, *Escherichia coli*, F-specific RNA coliphages, and somatic coliphages) and around 150 chemical parameters (including pharmaceuticals, personal care products, industrial chemicals, natural and synthetic hormones, polycyclic musks, and others). Furthermore, it is stated that each sample must “not contain detectable viral, bacterial or protozoan pathogens”.

The Regulation includes a specific standard relating to supply and storage for recycled water intended to augment a supply of drinking water. This standard facilitates indirect potable reuse but there is presently no formal position on direct potable reuse:

Recycled water intended to augment a supply of drinking water must be—

- (a) *supplied into an aquifer, lake, watercourse or wetlands, or a dam on a watercourse; and*
- (b) *stored under conditions that allow for sufficient management of any risk to the health of the public from the recycled water quality*

5.2.2 Western Australia

Western Australia stands out because it has been successfully operating an IPR scheme at Beenyup WWTP. The political and governance context of WA for IPR has previously been discussed by Bettini and Head (2016).

During the successful long term trial for the GWRS (see Section 2.7.2) some legislative and departmental barriers for a full scale IPR project were recognised. To resolve these, a working group was established between the Department of Health, Department of Environment and Conservation and Department of Water. The working group identified that a new approvals process needed to be developed and that at that point, clear definitions of recycled water treatment standards for IPR were not available within the state. It was also realised that there were legislative difficulties with the IPR scheme as the advanced treated water destined for the aquifer was still legally classified as wastewater. This issue of definitions was addressed with the introduction of the Public Health Bill 2014, which repealed and updated relevant sections of the *Health Act, 1911* (WA). This experience in WA, highlights the need to review in detail relevant water supply, recycling and disposal legislation as well as to encourage identify relevant departments and support interdepartmental collaboration.

The Trial provided information to help regulators to successfully address gaps in existing policy and regulations to enable groundwater replenishment to occur. This included:

- Defining “recycled water” produced by an AWTP for GWRS.
- Defining the process for identifying the environmental values (EVs) of the receiving aquifer and the water quality guidelines required to protect the EVs.
- Developing a process for determining the minimum distance between recharge of recycled water and abstraction for drinking (known as the Recharge Management Zone).
- The water resource regulator developing a managed aquifer recharge (MAR) Policy which described approval requirements for a MAR scheme.

The trial also included regulation specific to future GWRS recharging at the Beenyup site:

- Defining a minimum distance of 250m between recharge of recycled water and abstraction for drinking water applicable to Leederville aquifer and Yarragadee aquifer recharge bores at the Beenyup site.

Western Australia is currently undergoing significant reform on water supply related legislation. From August 2018, it was announced that six pieces of Western Australian legislation, the *Metropolitan Water Supply, Sewerage and Drainage Act, 1909*, the *Rights in Water and Irrigation Act, 1914*, the *Country Areas Water Supply Act, 1947*, the *Waterways Conservation Act, 1976*, the *Metropolitan Arterial Drainage Act, 1982*, and the *Water Agencies (Powers) Act, 1984* would be modernised and combined into one *Water Resources Management Act*. Among a host of other efficiency improvements, it was noted that managed aquifer recharge (IPR) will be specifically considered in the Water Resources Management Act and that available water options will be expanded and inconsistencies with the *Environmental Protection Act, 1986* will be addressed.

5.2.3 Other Australian states

There exist 'policy barriers' to potable reuse in a number of Australian states, as communicated on a few occasions by Premiers and state water ministers (see Chapter 6). However, there are no explicit legislative barriers to potable reuse. If/when plans for potable reuse eventuate, it may be reasonable to suggest that existing drinking and recycled water legislation could be applied together as they exist, in lieu of creating new overarching laws. As has already been noted, most state utilities and regulators support the use of the ADWG and AGWR (Matthews, 2015). In this section, relevant state legislation and government departments within the scope of both drinking water supply and water recycling are collated with an aim to identifying important stakeholders for a possible future review of policy and legislation.

Of all the states, NSW stands out on competition policy for water recycling due to the *Water Industry Competition Act, 2006* (NSW) (WICA). The WICA effectively provides a utility licence for smaller utilities (council and private) that is administered by the Independent Pricing and Regulatory Tribunal (IPART) in NSW. To obtain and hold a WICA licence, a small utility must demonstrate that they have appropriate technical and financial capacity to build and maintain a system capable of providing appropriate quantity (supply) and quality of water. WICA stands out compared to other states which operate on a government corporation model where cost is recovered over the life of water and wastewater services. It was noted that WICA type policy should reduce barriers to entry to private suppliers in the urban water sector and that this in turn may actually slow the transition to potable reuse by encouraging more initial private investment in non-potable uses instead, extending current potable supplies (Horne, 2016).

Legislation for water recycling and interested departments was extensively reviewed previously by Power (2010). The information from that review was reproduced in [Table 5](#) and best efforts made to update current departmental names and any new legislation. It is reasonably apparent from [Table 5](#) that legislation has evolved from an historic 'in and out' paradigm where drinking water supply and wastewater disposal were considered independently to be public health and environmental issues respectively. It should be noted that this paradigm does not apply to all states. For example, in South Australia, SA Health is responsible for regulation of both water and recycled water. Recycled water legislation, appears to build on wastewater legislation, which was generally overseen by environmental protection authorities. Given that potable reuse would close the loop, there may be cause to look at both sets of legislation and relevant departments together in an effort to optimise legislative requirements.

Table 5: State-based regulation for drinking water and recycled water and relevant departments.

State or Territory	Water Legislation	Recycled Water Legislation	Relevant Departments
ACT	<i>Public Health Act 1997</i> <i>Water Resources Act 2007</i> <i>Utilities Act 2000</i> <i>Utilities (Technical Regulation) Act 2014</i>	<i>Environmental Protection Act 1997</i> <i>Public Health Act 1997</i>	Environment, Planning and Sustainable Development Directorate Environmental Protection Authority ACT Health Directorate
NSW	<i>Public Health Act 2010</i> <i>Public Health Regulation 2012</i>	<i>Water Management Act 2000</i> <i>Local Government Act 1993</i> <i>Hunter Water Act 1991</i> <i>Sydney Water Act 1994</i> <i>Water Industry Competition Act 2006</i> <i>Water Industry Competition (General) Regulation 2008</i>	NSW Health IPART Department of Planning and Industry
NT	<i>Water Supply and Sewerage Services Act 2000</i> <i>Food Act 2004</i>	<i>Public Health Act 2005</i> <i>Waste Management and Pollution Control Act 1998</i>	Department of Health Environmental Protection Authority
QLD	<i>Water Supply (Safety and Reliability) Act 2008</i>	<i>Environmental Protection Act 1994</i> <i>Environmental Protection Regulation 1998 Schedule 1</i> <i>Water Supply (Safety and Reliability) Act 2008</i> <i>Public Health Act 2005</i> <i>Public Health Regulation 2005</i>	Department of Natural Resources, Mines and Energy
SA	<i>Safe Drinking Water Act 2011</i> <i>Safe Drinking Water Regulations 2012</i>	<i>Public Health Act 2011</i> <i>Public Health (Wastewater) Regulations 2013</i> <i>Environment Protection (Water Quality) Policy 2015</i> <i>Development Act 1993</i> <i>Environmental Protection Act 1993</i>	SA Health Environmental Protection Agency
TAS	<i>Public Health Act 1997</i>	<i>Environmental Management and Pollution Control Act 1994</i> <i>Land Use Planning and Approvals Act 1993</i>	Environmental Protection Agency Department of Health and Human Services
VIC	<i>Water Act 1989</i> <i>Safe Drinking Water Act 2003</i> <i>Safe Drinking Water Regulations 2015</i> <i>Water Amendment (Governance and Other Reforms) Act 2012</i>	<i>Environmental Protection Act 2017</i> <i>Environmental Protection (Scheduled Premises and Exemptions) Regulation 2017</i>	EPA Victoria Department of Health and Human Services
WA	<i>Water Services Act 2012</i> <i>Metropolitan Water Supply and Sewerage Act 1909</i>	<i>Environmental Protection Act 1986</i> <i>Environmental Protection Regulations 1987</i> <i>The Health Act 1911</i> <i>Metropolitan Water Supply and Sewerage Act 1909</i>	Environmental Protection Authority Department of Health Department of Water and Environmental Regulation

In NSW the approvals and licensing process appears to be cumbersome, with the relevant departments and legislation required differing, depending on whether a private utility (WICA) or larger utility (Sydney Water or Hunter Water) is operating a scheme. To further complicate the issue, regional council water supplies are administered by Department of Industry (DoI) Water whereas councils wishing to supply water within the Sydney or Hunter Water supply areas would have to apply for WICA. Although standing out on competition policy, the approvals process around water recycling in NSW seems to be different based on utility

size, ownership and geographical location. It is unclear how size, ownership and location should influence a standard of acceptable water quality. The large number of independent water supply utilities in NSW (more than 105 were counted in 2013 (Byrnes, 2013)), may also support a view that more streamlined legislation would result in efficiency improvements. At least in NSW, it may be pertinent to undertake a more detailed review of legislation in an effort to reduce inconsistencies in water approvals and management prior to considering potable reuse.

6

Readiness of the Australian Water Industry and Regulatory Frameworks

The success of the GWRS in Western Australia is sufficient evidence that potable reuse projects can be successfully planned and implemented in Australia. Although not yet operational as a potable reuse project, the successful construction and validation of the WCRWS in South East Queensland provides an indication that the opportunities for such successes are not limited to the west coast of Australia.

To assess the readiness of the Australian water industry and its regulatory frameworks (as described in Chapter 5) for the wider implementation of potable reuse, two important factors are briefly considered in this chapter. These are the current attention to urban water planning in Australia and the role of politics in potable reuse.

6.1 Current attention to urban water planning

During the recent period of relative water abundance after the end of the millennial drought, national policy priorities have turned away from urban water planning (Radcliffe, 2015). Intergovernmental and statutory institutional structures, such as the National Water Commission, have been abolished. Infrastructure Australia, a federal government agency, notes that water policy complacency is evident and reform impetus is at risk of being lost (Infrastructure Australia, 2017a).

The level of funding for research and development in the Australian urban water industry has declined markedly in recent years (Dillon *et al.*, 2018). A contributing factor has been the loss of a number of major water funding bodies, including the Australian Water Recycling Centre of Excellence (Burgess *et al.*, 2015; Radcliffe, 2015). However, recent analysis has indicated that Australian governments have much to learn from decisions to build very large potable reuse and desalination plants, particularly around timing and scale (Horne, 2016).

Infrastructure Australia has argued that there is a need to refocus regulatory perspectives for water in Australia, such that regulators focus on outcomes that work best for users (Infrastructure Australia, 2017b):

“As part of this, arbitrary restrictions on specific technologies or processes should be removed where they cannot be shown to address a clear risk to users. While there may be risks and community apprehension associated with processes such as potable reuse, this is no reason to prohibit this broad approach – as is currently the case in a number of states and territories. Service providers should be given the opportunity to prove that the risks of new approaches can be effectively managed, and to be able to engage communities directly to address any fears they may hold”.

This analysis indicates that the obstacles to potable reuse in Australia are, for the most part, not technical obstacles. That is, potable water reuse is not held up by a lack of capability for building or designing effective schemes. While skills may be limited within Australia, experience with seawater desalination plants around Australia and the Western Corridor Water Recycling Scheme has shown that for large capital city projects, most of the skills tend to be imported from Europe or the USA. There do not appear to be major obstacles to similar arrangements for future projects.

The capacity for acceptance of potable reuse by towns and cities outside of the state capitals, other than Toowoomba, has not been tested for potable reuse. The experience in Toowoomba, Queensland, during 2005-2006 is complex to re-analyse with many factors playing a role in the ultimate failure of that proposal. These included a situation in which a community plebiscite, requiring residents to vote for or against the proposed project, was imposed on the city by federal politicians. Nonetheless, that episode revealed that a local government water utility did not have the internal resource to explain to residents how technical issues, such as the management of potential water quality risks, could be competently and appropriately handled. It highlighted the need for a major focus on up-skilling and certification of key technical roles in water quality management for many regional cities. This would in turn increase the opportunities for consideration of alternative water sources.

By international standards, the water quality regulatory landscape in Australia is highly advanced and widely considered to be world-leading. Milestones such as the 2004 revision of the ADWG, as well as both Phase 1 and Phase 2 of the AGWR provide evidence for this reputation. The risk management frameworks, initially developed for incorporation in these Australian documents played a key role in shaping the Water Safety Plans, which now underpin both the WHO Guidelines for Drinking water Quality and the WHO Guidelines for Potable Reuse. Furthermore, representatives of the Australian state-based health agencies have been highly sought-after for leading roles in the development and updating of these international guidelines.

Despite this evidence of international leadership, the Australian water quality regulatory landscape is constrained in terms of personnel numbers. That is, the state-based health regulators tend to have very small teams focused on managing water quality risks. These teams are often composed of one or two senior people with many decades of experience and a handful of more junior staff with more specialised roles. As the more experienced senior staff approach retirement, it will be crucial that younger staff members are ready to succeed them. If formalised policies, practices and stable research funding arrangements are not in place to retain the significant leadership skills with the organisations, the ability to move forward with the ever-evolving landscape of water quality management will be hampered in the future.

6.2 The role of politics in potable reuse

Arguably, the most important difference, between states (such as Queensland and Western Australia) which have developed potable reuse schemes and those which have not, is the political landscape. In Western Australia in particular, support from all major political parties reduced any likelihood of high profile public opposition to the development of the Groundwater Replenishment Scheme.

Naturally, the decisions of democratically elected politicians will be influenced by a keen regard for community support, or lack thereof. In 2005, NSW Water Minister Frank Sartor effectively acknowledged this saying (Sydney Morning Herald, 2005):

“Recycling is a partial answer. We are doing it as much as we can, but we do not believe there is enough community acceptance to start piping water into the drinking water system,” and:

“The scientists are right but the scientists ought to get on talkback radio and persuade Sydneysiders that there won’t be a mishap”.

In 2010, the National Water Commission (Australian Government) issued a Position Statement on Urban Water Recycling which said (National Water Commission, 2010):

“The National Water Commission considers that water recycling – including for drinking purposes – can provide a significantly greater proportion of Australia’s future urban water supplies. The Commission argues that decisions on whether to use recycling for drinking purposes should objectively consider the risks, the costs and the benefits through a transparent and participatory process”.

With unprecedented population growth and climate change, Australian water utilities need to undertake robust long term planning for cost effective water security. However, the ability to do so may be impeded of pre-emptive State Government policy barriers to some water supply options, such as potable reuse, are in place. Recognising this, the National Water Commission in its 2011 Biennial Assessment stated (National Water Commission, 2011):

“Policy barriers restrict the choice of supply-side options and so potentially mean that the community does not have access to the most cost-effective supply security. Bans in place in parts of Australia include restrictions on rural–urban water trading, intercatchment transfers, new dams and indirect potable reuse”.

And further (National Water Commission, 2011):

“Another option that has been ruled out by a number of state governments is the reuse of water for potable purposes. Indirect potable reuse is technically possible for a range of locations and can be financially competitive compared to other supply options, particularly where there are no significant alternative”.

The Australian Academy of Technological Sciences and Engineering has also called for pre-emptive policy positions banning potable reuse to be reviewed (ATSE 2013):

“ATSE therefore concludes that [potable reuse] should be considered on its merits – taking all factors into account – among the range of available water supply options for Australian towns and cities. Furthermore, ATSE is concerned that [potable reuse] has been pre-emptively excluded from consideration in some jurisdictions in Australia in the past, and these decisions should be reviewed.”

“Governments, community leaders, water utilities, scientists, engineers and other experts will need to take leadership roles to foster the implementation and acceptance of any [potable reuse] proposal in Australia.”

This recommendation from ATSE was explicitly seconded by the Australian Government Productivity Commission in a recent Productivity Commission Inquiry Report on the topic of National Water Reform (Productivity Commission, 2017):

“All options should be ‘on the table’ — arbitrary policy bans should not be applied to specific supply options, as has occurred in the past in relation to irrigation-urban trade and direct potable reuse (chapter 4 and box 6.2, respectively). In particular, direct and indirect potable reuse should be considered on its merits and assessed against the same health standards as other water sources, rather than being arbitrarily banned due to the ‘yuck factor’.”

In “box 6.2” referred to in the above quote, the views of the Productivity Commission were further expressed with statements including *“While the social and political aspects of planned potable reuse — particularly DPR where recycled water is directly injected into a drinking water supply — need careful consideration, the case for an outright policy ban is weak”* and:

“While the cheapest water supply option is case-specific, foregoing the use of planned potable reuse can have significant economic costs. For example, the Toowoomba City Council’s decision to not use indirect potable reuse to augment its drinking water supplies required it to invest in a pipeline with a capital cost over \$100 million in excess of the estimated cost of the recycling proposal (PC 2011, p. 96)” (Productivity Commission, 2017).

Infrastructure Australia also released a report on “Reforming Urban Water”, calling again for an ‘all options on the table’ approach to water supply augmentation (Infrastructure Australia, 2017a):

“Long-term planning allows service providers to efficiently meet the needs of users. There may be a need for further investment in desalination plants to provide additional capacity in future. However, such investments should only be undertaken after other, less capital-intensive approaches have been considered. These may include other forms of supply augmentation, rural-urban water trade, making better use of recycled water for potable or non-potable applications, and demand-side measures such as wholesale scarcity pricing and water conservation efforts through incentives or enforcement”.

7

Community Perspectives Around Potable Reuse

Since the 1970s, numerous studies have been undertaken to characterise community attitudes to potable and non-potable water recycling in various countries, including Australia (Bruvold, 1988; Po *et al.*, 2004; Fielding *et al.*, 2018). These have generally indicated strong and widespread support for most non-potable applications, but lower levels of acceptance for potable water reuse.

To fully understand community attitudes to water recycling, it is necessary to consider instinctive and emotional responses that people have to human excrement and sewage issues. It has been illustrated that many people trust their own impressions of water quality, which are often based on cloudiness of the water, more than they trust medical and scientific evidence (Hartley, 2003). Cognitive factors such as the Law of Contagion and the Law of Similarity may explain many of these perceptions that people may have about water recycling (Haddad, 2004). The Law of Contagion suggests that once water has been in contact with contaminants it can be psychologically very difficult for people to accept that it has been purified. The Law of Similarity suggests that the ‘appearance’ of a substance’s condition or status is psychologically linked to perceptions of reality. Combined, these factors can create mental barriers to the acceptance of recycling water for drinking. These mental barriers have commonly been referred to as the “*yuck factor*” (Schmidt, 2008; Russell & Lux, 2009; Tennyson *et al.*, 2015).

Despite the inherent barriers to widespread community acceptance of potable reuse, the large number of international successful projects described in this report (see Chapter 2 and Appendix I), confirm that the barriers are not insurmountable. The WHO has stated 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 (WHO 2017). WHO states that a sustained and comprehensive public communication plan that addresses the health, safety and quality concerns throughout the various stages, from planning to implementation, is an essential tool to advance the success of projects.

7.1 Availability of information

Information needs to be made readily available to the public in a suitable form to support understanding of potable reuse proposals (WHO 2017). A recent Australian study tested the effectiveness of providing information about a potable reuse process and the safety of recycled water on cognitive, emotional and behavioural responses (Fielding & Roiko, 2014). The study found support for the hypothesis that providing information would result in more positive cognitive, emotional, and behavioural responses to recycled water. Information increased comfort with potable recycled water and, in general, participants who were provided with relevant information expressed more positive emotions, less negative emotions, more support, and lower risk perceptions than those not provided with information.

Decades of research have collectively confirmed that providing information about the recycling process, the safety of the source, the benefits of the source, that water recycling is practised in other places, together with other key aspects, increases acceptance of recycled water (Fielding *et al.*, 2018). Although not all members of the community will have the time or inclination to absorb the information provided, the knowledge that it is available is reassuring and extremely important for effective engagement. Those who are interested should be able to gain sufficient knowledge, which may help to reassure those they know who have doubts about the safety of potable reuse. The WHO (2017) has summarised key information areas that should be communicated to the public:

- **Water supply options available:** When formulating a water resources plan, it is important that problems of water shortages are clearly communicated and that all options are identified and evaluated. If the community thinks that some options have been overlooked, they will not trust the process. The goal of an engagement programme is not to promote potable reuse, but to ensure that it is understood, so that it can be considered together with other suitable options for augmenting drinking water supplies.
- **Planned vs *de facto* potable reuse:** The public is generally aware of the natural water cycle, but some are not aware of the practice of discharging treated or untreated wastewater into rivers (*de facto* potable reuse) which are used by downstream communities as sources of drinking water.
- **Contaminants (pathogens and chemicals) in drinking water from potable reuse systems:** The communicators must be prepared to answer technical questions about the nature of the contaminants (including pathogens and chemicals) in water. They need basic knowledge to be able to explain how control measures, including treatment technologies, can be used in multiple-barrier processes to inactivate or minimise contaminants. Community health officials and physicians should be included in the outreach process.
- **Technology:** Advanced treatment processes must be clearly explained in simple terms so that the public of all ages are able to fully comprehend what the technology can do, how contaminants in water are removed and how technical failures are detected and off specification water rejected.

Case studies of successful potable reuse projects reveal the importance of early and ongoing public outreach and engagement that target specific stakeholders and involve multiple mechanisms (Fielding *et al.*, 2018). The benefit of these approaches is that the engagement not only helps to build knowledge and understanding and address key concerns, but it also exemplifies fair procedures that could help build trust in the relevant authorities.

7.2 An understanding of the need

If communities are to accept a proposed potable reuse project, widespread understanding of the need for such a project is essential (Furlong *et al.*, 2019). Severe and immediate drought conditions often precipitate widespread awareness of the need for water supply augmentation. However, such a state of urgency is often not conducive to the long-term planning and preparation required for the successful implementation of a potable reuse project. Thus there is a need for communities to understand the longer-term perspectives around population growth, climate change, and their impacts on future water shortages.

During construction of the Western Corridor Recycled Water Project in Queensland, the State Government commissioned some professional telephone polling to gauge support. The following questions were posed to 800 voters (Galaxy Research, 2008):

“In February the first part of the government’s water grid is due to come on line. This will include the recycling of wastewater in South East Queensland. Do you support or oppose the inclusion of purified recycled water in the new water grid? Would you support or oppose the inclusion of purified recycled water in the new water grid if it was only to be used as a back-up when dam levels dropped below 40%?”

In response to these questions, 54% of people stated that they supported the addition of recycled water to the drinking water supply as a general strategy and an additional 28% stated that they supported the scheme as a back-up measure (Galaxy Research, 2008). The remaining 18% opposed the use of recycled water for drinking water supplementation. This suggests that, on top of a base level of support, considerably more convincing support was based on a clear understanding that the water would only be used in a serious water shortage scenario, possibly at some time in the future.

7.3 Timing

Attitudes to water recycling tend to solidify over time, indicating the importance of early, accurate information (Ching & Yu, 2010). Hurlimann and Dolnicar (2010b) reviewed the failed Toowoomba potable reuse project and concluded that opponents had benefited from a ‘First Mover Advantage’. In this case, the opponents had been the first to communicate with the public and negative information became the benchmark. Over time, it became even more difficult to communicate any positive messages to the public.

However, negative information about water recycling has also been found to be taken seriously by the public no matter whether it was presented before or after positive information about water recycling (Kemp *et al.*, 2012). Kemp *et al.* (2012) suggested that the most

likely reason was that, because water is a fundamental human need, any change in supply was likely to be perceived as high risk.

However, Kemp *et al.* (2012) also found that there might be a ‘recency effect’ with water recycling messages. Attitudes tended to change in the direction of the most recent information campaign. This suggests that water-recycling projects need sustained and frequent positive information campaigns or else public attitudes may be swayed by negative information. Nellor and Millan (2010) advise that water reuse organisations should ‘never stop your outreach efforts even if the project is successfully under way’.

Both the need and timing were important when getting potable reuse back on the table in San Diego. As discussed in Section 2.2, a proposal to introduce potable reuse failed in the late 1990s due to a lack of community support. Over the course of 16 years, public opposition to water recycling softened from 63% in 2004 to 25% in 2011 (Barringer, 2012) and finally in 2014 The City Council vote in support of water recycling occurred. It is difficult to quantify exact time required for acceptance, but this example highlights that it may be necessary for long term community engagement before potable reuse options can be considered by a community on an equal footing with other water security options.

7.4 Language

Research indicates that specific words used to communicate water recycling messages, both positive and negative, have a strong influence on public perceptions (Fielding *et al.*, 2018). Different language may be necessary to deliver targeted messages because different stakeholder groups tend to frame water recycling issues differently (Stenekes *et al.*, 2006). However, it has been argued that the terminology currently used to communicate water recycling messages has been inconsistent, confusing, and difficult for the general public to understand or, worse, may have unnecessarily alarmed the public (Marks & Zadoroznyj, 2005; Tsagarakis *et al.*, 2007; Simpson & Stratton, 2011).

Menegaki *et al.* (2009) found that the use of ‘recycled water’ instead of ‘treated wastewater’ increased end users’ willingness to use the water because treated wastewater had a negative emotional impact. Further, Simpson and Stratton (2011) found that words such as ‘pure’ and ‘purified’ improved confidence, whereas words such as ‘recycled’ and ‘reclaimed’ had negative impacts. This is supported by research from the USA, suggesting that terms such as ‘purified water’ or ‘advanced purified water’ should be used to describe the potable reuse product (Tennyson *et al.*, 2015). Unfamiliar terms such as ‘potable’ instead generated mistrust (Simpson & Stratton, 2011).

With respect to direct potable reuse, care may need to be taken to ensure that messages compensate for the perceived loss of the

environmental buffer, since the public may respond less favourably to the idea of 'artificial' processes like advanced treatment technologies than to 'natural' processes like an environmental buffer (Rozin & Nemeroff, 1990; Nellor & Millan, 2010).

It has been suggested that terminology and messages should focus on the quality of the water, not the history of where the water has been, i.e. not its source as wastewater or how it has been used, but what the water can safely be used for (WHO 2017). Messages that support the quality of the water can include those which emphasise the amount of monitoring and testing which will be undertaken to ensure that the water will meet appropriate national and international standards and that the scheme has the support of the relevant regulatory agency.

7.5 Knowledge of urban water cycles

Research undertaken in the USA and Australia has revealed that community perceptions of potable reuse can be significantly influenced by enhanced knowledge regarding some realities of urban water cycles (Furlong *et al.*, 2019). For example, it was found that 23 to 28% of focus group participants preferred direct potable reuse over three other hypothetical reuse scenarios once they understood that drinking water often comes from rivers containing wastewater from upstream WWTPs and agricultural runoff (Macpherson & Snyder, 2013). Keys to acceptance were the language, concepts, and context that researchers used to explain the water cycle and treatment scenarios.

This research explored the hypothesis that approaching the concept of potable reuse from an overall urban water cycle context may overcome the stigma and disgust that arises from the typical approach of describing the water as originating in a WWTP. It showed that overcoming linear thinking related to water use appears to help promote acceptance of potable reuse. Water from a planned potable reuse project that included treatment at a water purification plant downstream of a WWTP was preferred by survey respondents more than three times as often as water from a business-as-usual *de facto* potable reuse project that did not include a water purification plant.

In a qualitative survey, participants were asked whether they thought that the drinking water from various scenarios of *de facto* and planned potable reuse was "very safe", "safe", "low safety" or "unsafe". In all cases, a large majority (>70%) of both Americans and Australians thought that drinking water was either "safe" or "very safe".

A second question asked the participants about their willingness to drink the water in each of the scenarios. Again, a large majority (>70%) were either "very willing" or "generally OK" with drinking the water in each scenario. In both countries, the lowest scores were for *de facto* potable reuse, presented as "current practice". Among the

key findings was that an awareness that drinking water can come from rivers containing wastewater from WWTPs had an immediate positive impact on a participant's view of planned potable reuse.

7.6 Societal legitimacy versus technical capability

A recent study analysed some existing cases of adoption of potable water reuse based on concepts of societal legitimacy, which is the generalised perception or assumption that a technology is desirable or appropriate within its social context (Harris-Lovett *et al.*, 2015). The Orange County Groundwater Replenishment System was put forward as an example of a "legitimised" potable reuse project. Proponents of this project engaged in a portfolio of strategies that addressed three main dimensions of legitimacy. In contrast, other proposed projects that faced extensive public opposition relied on a smaller set of legitimisation strategies that focused near-exclusively on the development of robust water treatment technology. The authors concluded that widespread legitimisation of potable water reuse projects may require the establishment of a portfolio of standards, procedures, and possibly new institutions.

7.7 The role of water recycling visitor centres

Visitor centres have been a valuable and effective aspect of some successful potable water recycling projects. A well-planned visitor centre can offer a wide range of opportunities for community engagement and education.

A pioneering example was the Singapore NEWater Visitor Centre, opened in 2003 by Singapore's national water agency, the Public Utilities Board. Interactive models, games and videos are used to describe the water recycling process at a range of technical levels. All visitors are presented with a 'bottled water' sample of recycled water on arrival. Through large glass windows, the visitors can see the key components of the advanced treatment process (MF and RO) and observe the plant operators undertaking their duties. The centre caters primarily for a domestic audience, with large numbers of school student tours, but is also a well-advertised attraction for international visitors.

Following the example of Singapore NEWater, educational visitor centres have been developed adjacent to a number of AWTPs in Australia. Prominent examples include the Vortex Education Centre at the Gippsland Water Factory located in regional Victoria (Atrium, 2011), Sydney Water's St Marys Water Recycling Education Centre located at St Marys water recycling plant and Water Corporation's Groundwater Replenishment Visitor Centre in Craigie, WA (Brown,

2018). Each of these hosts visits by school excursions and other interested community members. A systematic study of quantifiable success factors for visitor centres has not been identified and there is uncertainty on the best ways to measure success of these centres.

In 2009, the City of San Diego established a Water Purification Demonstration Project to examine the viability of a major proposed potable reuse scheme for that city (Steirer & Thorsen, 2013). Studies examining treatment performance and process reliability were completed in 2013, but the Demonstration Project continues to perform public outreach activities.

7.8 Available community engagement resources: Water360

The Australian Water Recycling Centre of Excellence initiated the Water360 partnership to contribute to an ongoing sharing of information and knowledge about potable reuse as a safe, reliable and cost-effective option for water security. The key outcome is the 'Water360' collection of education products designed to help water utilities, municipal councils, universities and government organisations with their water education and customer engagement programs. The Water360 resources were collated between 2011 and 2014, during an AWRCoE research project, and interviews were typically conducted within this period, however, some of the resources were primary material taken from Water Factory 21.

Water360 education products were designed to be flexible and adaptable to a diversity of geographic settings and cultural contexts. The materials can be adapted to incorporate local content and context, be combined in various ways, and linked to school curricula or existing utility educational materials and programmes. The materials are also adaptable to multiple display platforms such as kiosks, long-form documentaries, video walls, interactive screens, social media and phone and tablet applications. Water360 also includes a global connections map which explains the need for potable reuse, the benefits of reuse, its reliability and treatment processes. Video stories are told in various ways, with people from all walks of life area – from recycled water plant managers to citizens.

The Water Replenishment District of Southern California is one example of a US water agency, which has adopted products from Water360. The Water Replenishment District was formed in 1959 to manage the groundwater replenishment and groundwater quality activities for 4 million people in 43 cities that overlie the Central Basin and West Coast Basin in southern Los Angeles County. Their main office is in Lakewood, California and is home to a number of highly prominent Water360 displays. As visitors enter the office, they approach a large globe, situated in the centre of the reception area,

as shown in Figure 3. The globe is touch-sensitive and interactive. Visitors are presented with a world map, showing locations of important potable reuse projects. From those, they may selectively access more information, including text and video material. The example shown in Figure 3, features two people discussing their important roles with the development and approval of the of the GWRS in Perth, Western Australia (Richard Theobald from WA Department of Health and Nick Turner from Water Corporation).



Figure 3: An example of a Water360 product in the reception area of the Water Replenishment District of Southern California.

Water360 products include:

- A Global Connections Map platform currently featuring 23 water stories around the world.
- 'Think and Drink Water' animated videos on water futures, water citizenship, sustainability, systems thinking, designed-for-purpose, and assessing information.
- A Water Cycle Explorer video on the urban water cycle.
- Videos and animations on the science of water treatment.
- International experts in Australia, USA, Africa, Singapore and Europe discussing issues such as water security, potable reuse, water quality, water economics, wastewater, public engagement.
- Guides, fact sheets and technical reports on potable reuse.

Organisations interested in access and/or adapting some of these materials to support current or future potable reuse projects may do so by becoming a Water360 partner or subscriber. More information is available via the Water360 website: www.water360.com.au. Ongoing management of Water360 material is now undertaken by the Water Services Associated of Australia (WSAA).

8

Pathways to Support Successful Potable Reuse in Australia

Given the strength of the drivers and incentives for potable reuse, it is anticipated that there will be pressures on Australian towns and cities to develop potable reuse projects during the next couple of decades. Given this high likelihood, it has been argued that it is “disingenuous” for public authorities to present the possibility of future potable reuse projects (and other water supply augmentation projects) as some sort of choice for the community to make. Furlong *et al.* (2019) make this point clearly:

“Public authorities are pressured both to plan for long-term water security through climate-independent sources and to interact with the public and be responsive to what the public wants. It seems disingenuous, therefore, to frame water security issues in terms of “determining what the public actually want” and “a broader set of potential solutions”, when in reality water-stressed cities will eventually turn to these technologies out of necessity. In some locations, depending on water resource and climate conditions, little will be gained from a pretence that potable reuse and desalination are choices when their implementation is inevitable. In this context, governments and public authorities will need to start framing these issues honestly (e.g., “it’s only a matter of time before we have to do it”) and confidently (e.g., “it is 100% safe and implemented all over the world”).”

Until changes to support the successful development of potable reuse can be effected, long-term water planning for many Australian towns and cities will remain stymied. Cities and water utilities planning transformational change projects, such as potable reuse, should consider the establishment of appropriate adaptive pathways to effectively achieve change. For example, Melbourne water corporations (Melbourne Water, Yarra Valley Water, City West Water, South East Water and Western Water) have adopted an adaptive pathway planning framework centred around “Knowledge, Values and Rules”, as articulated in the Melbourne Sewerage Strategy. This involves working to ensure an alignment between the organisations’ technical understanding (Knowledge), social norms (Values) and regulatory settings (Rules).

8.1 A national strategy for urban water management

The Intergovernmental Agreement on a National Water Initiative (NWI) was signed between the Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory in 2004. Tasmania and Western Australia also joined the NWI in subsequent years. The NWI was the most recent document that can be considered to provide a national strategy for water management generally.

The focus of the NWI was the improved management of water in rural and regional communities, particularly the Murray-Darling Basin. Urban water management was included but was dealt with only very briefly. Nonetheless, among the seven listed objectives for urban water reform was to “encourage the re-use and recycling of wastewater where cost effective”. The National Water Commission (NWC) was established in 2005 to oversee and progress the implementation of the objectives of the NWI.

From 2006, the NWC undertook a series of major projects and produced reports, aimed at progressing the viability of potable reuse projects in Australia. However, the NWC was abolished in 2014. Some of the roles of the NWC were transferred to the Productivity Commission, but no agency has taken on clear responsibility for overseeing any further progression of the NWI. Consequently, progression of the NWI has slowed and is largely unmeasured (Productivity Commission, 2017).

There is a need to re-establish a national strategy for urban water management. This would be a strategy jointly agreed to by the Commonwealth with the state and territory governments. The range of potential benefits that might flow from such a strategy is beyond the scope of this report but could include a consistent and coherent approach to assessing opportunities and planning for potable reuse projects.

Consistent terminology, application of communication strategies, and risk management programs would all be highly advantageous for the efficient development of potable reuse opportunities. Furthermore, a national strategy would facilitate the identification of national research priorities, thus improving the targeting of research funding to address key knowledge gaps.

8.2 AGWR (Phase 2) to merge with Australian Drinking Water Guidelines

The Australian Guidelines for Water Recycling were developed in two “phases”. The AGWR (Phase 1) were published in 2006 and addressed water recycling for non-potable applications only. The ‘ownership’ and ongoing responsibility for these guidelines was established by their endorsement by three national bodies: The Natural Resource Management Ministerial Council, The Environment Protection and Heritage Council, and the Australian Health Ministers Conference.

The AGWR (Phase 2) were published in 2008 and built upon the basic concepts presented in the AGWR (Phase 1), with specific focus on issues relating to planned potable reuse. The NHMRC is the national body that maintains oversight and responsibility for

the Australian Drinking Water Guidelines (ADWG). Since the AGWR (Phase 2) addressed drinking water production, it was appropriate that NHMRC assume responsibility, and thus the NHMRC endorsed the AGWR (Phase 2), replacing the Australian Health Ministers Conference that had stepped in to endorse AGWR (Phase 1).

A decade after the AGWR (Phase 2) were developed, there appears to be no active 'ownership' and no process in place to maintain currency of the document. The two Ministerial Councils which initiated the preparation of the AGWR, the NRMCC (succeeded by the Environment and Water Ministerial Council) and the EPHC were abolished on 13 December 2013 (Abbott, 2014) and their successors including the Environment Ministers Council and the Agricultural Ministers Forum have no specified water responsibilities.

On the other hand, the ADWG are actively maintained by the NHMRC and major new developments, such as the application of 'health based targets' for microbial water quality, are anticipated in the coming few years. These developments will be directly relevant to the AGWR (Phase 2), and many should be automatically carried through.

It is proposed that a future revision of the AGWR (Phase 2) be planned, whereby this document is amalgamated with the ADWG. To achieve this, the AGWR (Phase 2) could be presented as an additional second Volume of the ADWG. In this case, it should be clearly implied that all the information presented in the ADWG is also applicable to potable reuse. Thus, the new Volume specifically addressing potable reuse could be significantly abbreviated from its current form, to only include additional guidance applicable specifically to potable reuse.

Amalgamation of the AGWR (Phase 2) into the ADWG would ensure that ongoing revision and updating is achieved, as it currently is for the ADWG. It would also ensure consistency between the two documents.

8.3 Enhanced water quality safety culture in the Australia

The provision of safe drinking water should be reinforced as the primary responsibility of all drinking water providers. Utilities carry other important responsibilities including good business management, fiscal responsibility and the production of dividend payments to shareholders including governments. However, it is important that these business-related responsibilities are never elevated to such a level that they risk impacting the reliable supply of safe drinking water.

The development of planned potable reuse projects will require that a water quality safety culture be actively and robustly

maintained by all responsible organisations and the industry as a collective (Binz *et al.*, 2018). A safety culture must be embedded at the very top levels of governance in an organisation. One way to achieve this would be to require that, where present in the utility structure, all governing boards of water utilities include members possessing various specific skills, qualifications and experience. As an example, the *Sydney Water Act, 1994 (NSW)* requires that the board of the Corporation consists of a number of directors "who are to have appropriate expertise, to the intent that the board includes directors with separate expertise in at least the following areas: (i) business management, (ii) protection of the environment, (iii) public health".

Furthermore, it has been argued that an enhanced industry-wide water quality safety culture should be developed, following examples of other industries, such as the aviation and oil and gas industries (Binz *et al.*, 2018). These examples suggest that a long-term adaptive process must be established to capture and learn from minor errors and deviations from standard procedures. The transparency around the communication and sharing of these errors and quality near misses is critical to their uptake and consideration to better inform future risk management. Already in some states, water utilities register and report such deviations on a voluntary (and non-penalised) basis, and regulators require reporting and data sharing. Regulatory interventions must allow for stringent oversight, but also enable adaptive flexibility so the industry can continually improve safety standards.

8.4 Policy positions of state governments and opposition parties

Even in circumstances where potable reuse may not prove to be a component of an optimum water supply portfolio for a particular town or city, it remains preferable that this option is available for open and transparent comparison with other alternative water supply strategies.

An example of a cooperative approach was observed in Western Australia, home to the successful Groundwater Replenishment Scheme (GWRS). The concept of the GWRS was conceived, and a three-year trial project was run, under a Labor Government during 2007-2012. Evaluation of the trial outcomes and a decision to move ahead with the construction of the full-scale GWRS coincided with the 2013 WA election, which resulted in a change of government. The newly elected Liberal-National Government announced the success of the trial and plans for full-scale construction just months after being elected. The success of this project rests heavily on the confirmed support from each of the three major political parties (Labor, Liberal and National) throughout its development.

9

Acknowledgements

This report was produced by funding provided by Water Research Australia, for the project “Potable Reuse Update”. WaterRA Project Number 3039-17.

10

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Appendix I – Global Examples of Planned Potable Reuse

There are a significant number of pioneering and recently developed planned potable reuse projects that underpin current knowledge and capability for potable reuse. Key details for some of the most important projects from the USA, Singapore, Namibia, Belgium and Australia are presented in this Appendix.

10.1 Montebello Forebay, California, USA

Potable water supplies have been intentionally replenished with recycled water (as well as urban stormwater) in Los Angeles County of California since the 1960s (Gasca & Hartling, 2012). The Montebello Forebay Groundwater Replenishment Project (MFGRP) is located within the Central Groundwater Basin in Los Angeles County, where the Districts' recycled water, blended with imported river water and local storm runoff, have been used for replenishment since 1962.

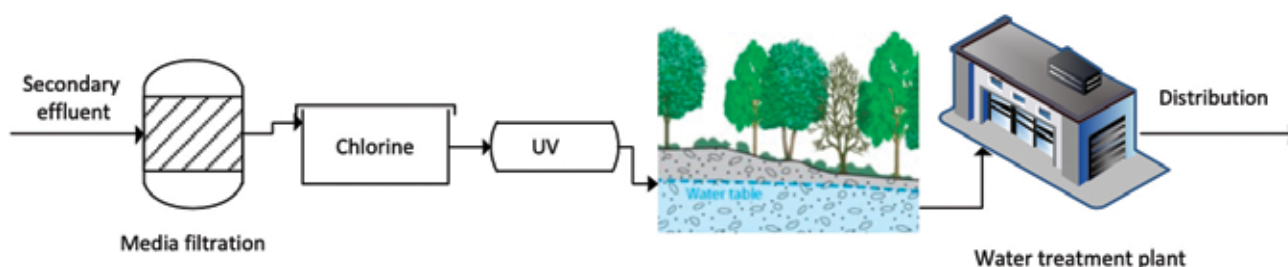
In the 1950s, following a rapid population growth in the region, excessive and unregulated pumping resulted in depressurisation of the groundwater table and allowed seawater to intrude into the

aquifer. In response, the Water Replenishment District of Southern California was formed to manage this basin by regulating pumping and purchasing supplemental water supplies for replenishing the groundwater.

Municipal wastewater from a newly constructed local secondary WWTP was chloraminated to meet the California Department of Health requirements for groundwater recharge. The successful reuse of water from this plant led to the decision to construct additional plants in the Los Angeles area in the 1970s, two of which also now contribute to the recharge of the Central Basin. In 1977 media filtration was added to the treatment process to enhance virus inactivation during final disinfection. In the early 2000s, the plants were upgraded again, to provide nitrification/denitrification. Finally, in 2011, UV disinfection was installed for enhanced pathogen control, however it's unclear whether all of the water used for groundwater replenishment undergoes UV treatment.

Blended urban stormwater and recycled water are returned to the groundwater supply through dedicated percolation basins that are operated to maintain a distinct vadose zone (unsaturated zone) between the top of the water table and the ground surface. Process flow diagram for the potable reuse aspect of the project is presented in [Figure 4](#).

Figure 4: Process flow diagram for the Montebello Forebay potable reuse project.



Water is percolated into the groundwater using two sets of spreading grounds (the Rio Hondo Coastal Spreading Grounds and the San Gabriel Coastal Spreading Grounds) and within portions of the San Gabriel River, where water flow may be retarded by the use of inflatable dams. The spreading grounds are operated under a wetting/drying cycle designed to optimise inflow and discourage development of vectors (Gasca & Hartling, 2012).

A five-year health effects study was initiated in 1978 to evaluate possible health effects from the MFGRP (Nellor *et al.*, 1984; Nellor *et al.*, 1985). At the time of the study, recycled water comprised around 16% of the total inflow to the groundwater basin. Results of the study showed that the proportion of recycled water currently used for replenishment had no measurable impact on either groundwater quality or human health.

Based on the results of the health effects study and recommendations of the State of California Scientific Advisory Panel (Robeck, 1987), authorisation was given in 1987 by the Regional Water Quality Control Board to increase the annual quantity of recycled water used for replenishment. The water reclamation requirements for the project were revised again to allow for even greater recharge volumes and up to 50% recycled water in any one year providing that the running three year total did not exceed 35% recycled water. In 2018, the Los Angeles County Sanitation District continues to divert tertiary quality wastewater and captured stormwater into the groundwater recharge basins in the Montebello Forebay. This water contributes to the groundwater supply in Los Angeles County.

10.2 Groundwater Replenishment System, Orange County, California, USA

The Orange County Water District in California has been pioneering planned potable reuse since the establishment of the now superseded “Water Factory 21” project in 1976 (Wetterau *et al.*, 2013). The Water Factory 21 AWTP had been treating municipal wastewater by reverse osmosis since 1976 and incorporated high energy UV treatment for NDMA destruction in 2001.

The Water Factory 21 plant was decommissioned in 2004 due to the need to expand capacity and to introduce updated treatment technologies. Construction of the Groundwater Replenishment System (GWRS) was subsequently jointly funded, and now operated, by the Orange County Water District and the Orange County Sanitation District of Fountain Valley, California. It is now the world’s largest water purification system for potable reuse.

The GWRS takes wastewater that would have previously been discharged into the Pacific Ocean and purifies it by MF, RO and UV/H₂O₂ (Figure 5). The recycled water is then used to recharge underground drinking water supplies in Orange County, California. Operational since 2008, the GWRS has a current capacity to produce up to 350 ML/day of recycled water. There are now plans in place to expand this to a production capacity of 500 ML/day. Construction for this expansion is expected to begin in 2019 and to be completed by 2023.

Figure 5: Process flow diagram for the Groundwater Replenishment System, Orange County, California.

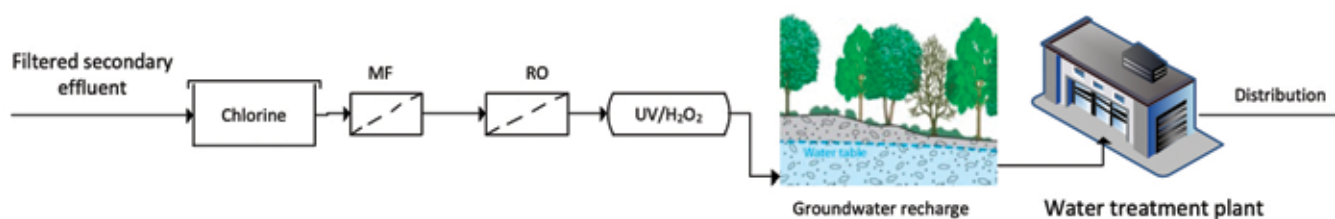
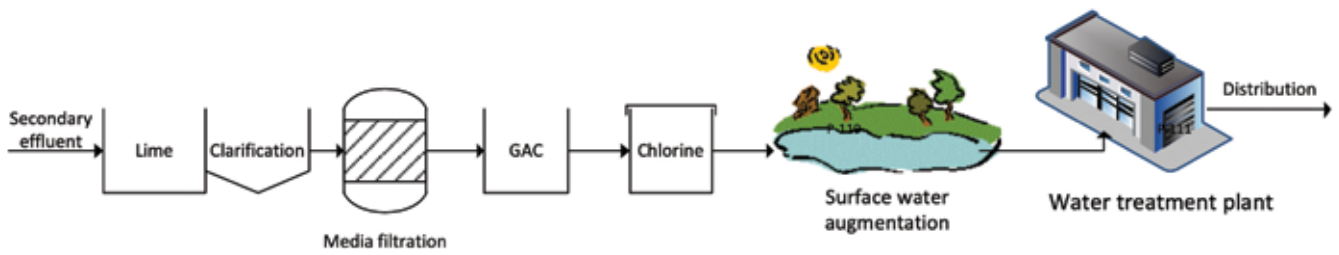


Figure 6: Process flow diagram for the Upper Occoquan Service Authority potable reuse project.



Approximately half of the recycled water currently provided by this facility is applied to surface spreading basins, and the remainder is used to maintain injection wells of the Talbert Gap Barrier to protect an important groundwater aquifer from seawater intrusion by the Pacific Ocean.

The California Division of Drinking Water Title 22 Regulations require that groundwater recharge potable reuse projects must achieve at least 12 Log₁₀ enteric virus reduction, 10 Log₁₀ *Giardia* cyst reduction, and 10 Log₁₀ *Cryptosporidium* oocyst reduction (California Office of Administrative Law, 2019). A precise treatment train to achieve this is not stipulated. However, at least three separate processes must be credited with at least 1 Log₁₀ reduction for each pathogen. Furthermore, any engineered treatment processes may be credited with a maximum of 6 Log₁₀ reduction for each pathogen. These requirements made the incorporation of either UV-disinfection or UV/H₂O₂ an attractive option for inclusion in the overall GWRS treatment train.

In addition to meeting virus Log₁₀ removal requirements for Title 22 Regulations, the principle reasons for inclusion of the AOP were for photolysis of N-Nitrosodimethylamine (NDMA) and advanced oxidation of 1,4 dioxane and any other remaining trace organic chemicals after RO treatment.

The GWRS has played an important role in establishing best practice for community outreach and stakeholder engagement for potable reuse (WHO 2017). An outreach campaign was conceived in 1997, a decade before the project came online. A public outreach consultant was hired, and initial research was conducted consisting of focus groups and telephone surveys. From this research, key issues and target stakeholder audiences were identified.

Initial outreach efforts focused on informing political and community leaders of the project details and building a foundation of understanding and support. Subsequent phases broadened these efforts to reach the general public. From 1997 to 2007, more than 1000 face-to-face presentations focusing on the technology of the GWRS were given to local, state and federal policy-makers, business and civic leaders, health experts, environmental advocates, academia and the general public. Other communication materials were also developed, including letters, newsletters, brochures, and videos. Four public workshops were held across Orange County to receive citizen input prior to the decision in 2001 to proceed with the final engineering design.

A recent study examined local, national and international newspaper coverage of the GWRS during 2000-2016 (Ormerod & Silvia, 2017). The study found that despite the potential controversy during this period of large expansion of potable reuse, there was no negative newspaper coverage. While much of the coverage was mundane, several articles were found to have embraced infrastructure and technology as keys to developing new water resources while protecting public and environmental health.

10.3 Upper Occoquan Service Authority, Virginia, USA

The pioneering potable reuse project to use surface water augmentation in the USA was led by the Upper Occoquan Service Authority (UOSA) in Virginia (Angelotti & Grizzard, 2012). Motivated by population growth, increasing urbanisation, and a declining water quality of the Occoquan Reservoir, the major raw water supply for northern Virginia, the UOSA water reclamation system was established in 1978.

The Occoquan Reservoir is a critical component of the water supply for approximately 1.5 million residents of Northern Virginia, a highly urbanized region located west of Washington, DC. By the mid-1960s, increasing urbanisation was adversely affecting water quality of the Reservoir, resulting in a *de facto* potable reuse scenario, where 11 small WWTP were discharging wastewater upstream of the reservoir. In 1971, the Virginia State Water Control Board and the Virginia Department of Health established a plan to protect the Occoquan Reservoir as a drinking water supply. The Occoquan Policy mandated a new framework for water reuse and underscored the establishment of the first planned and intentional use of recycled water by surface water augmentation in the USA (State of Virginia, 2018). While water quality improvement was the primary driver for implementing planned and intentional potable water reuse in the Occoquan system, supplementing the raw water supply was always an underlying objective (Angelotti & Grizzard, 2012).

Prior to surface water augmentation, the water reclamation processes include secondary treatment with biological nitrogen removal. Lime precipitation and clarification are used to remove phosphorus and also act as barriers to pathogens and heavy metals. Additional treatment is provided by multimedia filtration, GAC adsorption and chlorine disinfection. The current water reclamation facility has a capacity of 200 ML/day.

Recycled water from the UOSA facility is discharged into a tributary of the Occoquan Reservoir. The discharge point is approximately 10 km upstream of the headwaters of the reservoir and 30 km upstream of the drinking water supply intake. Recycled water typically accounts for less than 10% of the annual average inflow to the reservoir, but during drought conditions may account for up to 90%. The overall potable reuse project is illustrated in Figure 6.

The Occoquan Reservoir is a run of the river impoundment, and as a result, has high seasonable variability in residence time, which is further affected by the significant withdrawals for drinking water production. The average residence time is less than 30 days, but storm flows, and the combined effects of drought and pool drawdown, can produce very large departures from that value.

In 2006, the existing drinking water treatment plant was replaced. The new plant provided a major upgrade in treatment technology. These now include enhanced metal salt coagulation, flocculation and settling, ozonation, biological activated carbon filtration and chloramination. Currently, the drinking water plant has a treatment capacity of 450 ML/day. After 40 years of successful operation, the Occoquan project is seen globally as a pioneering effort in potable reuse (WHO 2017).

10.4 Gwinnett County, Georgia, USA

The major wastewater facility in Gwinnett County, Georgia, USA is the F. Wayne Hill Water Resources Centre (FWH WRC). This is one of three County owned and operated facilities and provides waste water services to more than 50% of the population (Funk *et al.*, 2018). During planning, it was recognised that the population of Gwinnett County was growing rapidly and as of 2006, it was

necessary for the FWH WRC to be upgraded from an initial total treatment volume of 80 ML/day (Phase 1, completed in 2000) to a total flow of 230 ML/day (Phase 2, completed in 2006).

Wastewater at FWH WRC undergoes screening and grit removal, primary settling and is then treated with activated sludge and clarification, producing a secondary treated wastewater. The Phase 1 scheme at FWH WRC utilised an advanced treatment train consisting of solids contact and chemical clarifiers, followed by media filtration. The filtrate was then sent through pre-ozonation, biological activated carbon and post ozonation (Funk *et al.*, 2018). This treated Phase 1 treated wastewater was then disposed into Lake Chattahoochee, with some used for irrigation. During design, environmental modelling determined that Lake Chattahoochee could not accommodate the additional 150 ML/day of treated wastewater from the planned scale up of Phase 2. A suitable discharge point for Phase 2 was determined to be Lake Lanier, but within the vicinity of a drinking water treatment plant intake. With Phase 2, iron coagulation and settling followed by ultrafiltration (UF) membrane filtration were selected as the pre-treatment for increased capacity ozone, BAC, ozone (Funk *et al.*, 2018). A potential reason for UF selection with the upgrade was more consistent quality when compared to media filtration. The process presently at FWH WRC as reported recently is illustrated in Figure 7.

Figure 7: Process flow diagram for the Gwinnett County potable reuse project.

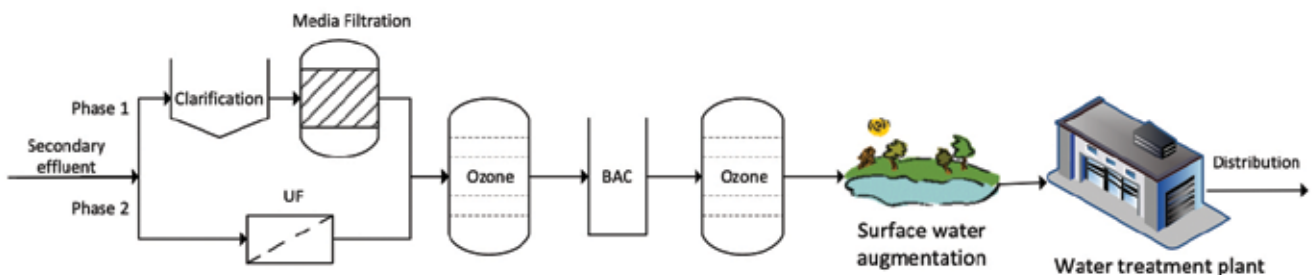
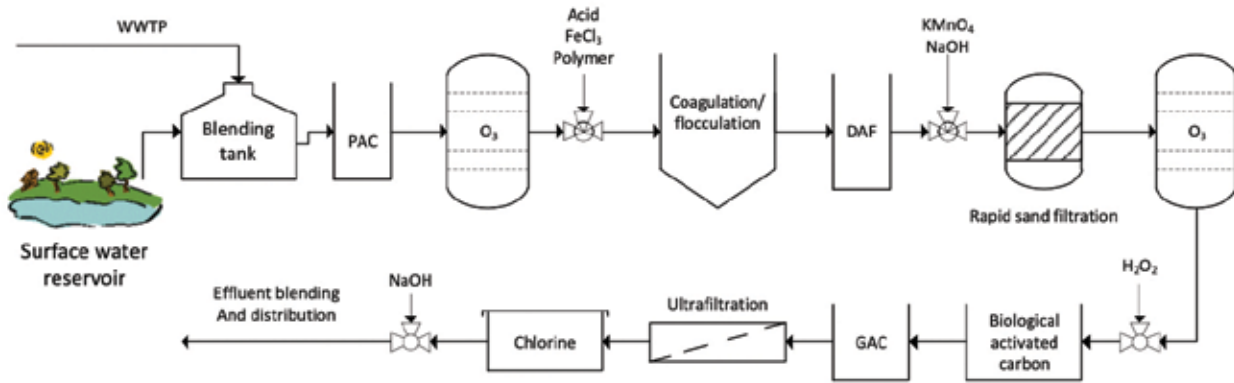


Figure 8: Process flow diagram for the NGWRP.



In addition to operating one of the largest membrane ozone based AWTPs in the world, FWH WRC stands out due to the absence of a RO process. It is not clear why RO was not selected for the FWH WRC train, but some motivations have been explored. In a recent study, it was reported that RO schemes produce concentrated brine stream which incurs additional concentration and disposal costs, to an already expensive process. Indeed, when the AWTP flowsheet of Gwinnett County was compared to Oxnard California (UF, RO, UV/AOP) and both were scaled to treat 90 ML/day of wastewater it was predicted that capital and operating costs of the ozone BAC arrangement were both approximately 40% lower (Lozier, 2016). This study neglected brine disposal, hence the cost difference between both options in reality would likely be higher, if feasible and environmentally sustainable disposal options were available. Also, the maximum recovery rate of RO is typically lower compared to adsorption processes such as GAC, which only lose a small fraction of recovery, proportional to backflush requirements.

As well as cost comparison, it is clearly important to compare chemical and microbial quality from the schemes. Validated log removals were compared between Oxnard and FWH the MF, RO and UV/AOP were credited with a total of 11 for protozoa and 9 - 10 for virus, while the FWH WRC was accredited with 5 - 7 for protozoa and 8 for virus. Importantly, only post ozonation and UF were accredited at FWH WRC, meaning the contribution of pre ozonation and filtration performance of BAC were ignored. If a UV/AOP process was incorporated into the FWH WRC and accredited with the typical values of 6 for protozoa and viruses, the validated water quality of the BAC process could potentially reach 12 - 13 for protozoa and 12 for viruses, exceeding the typical MF/RO/UV/AOP treatment capacity (Lozier, 2016).

10.5 Goreangab Water Reclamation Plant, Windhoek, Namibia

Since 1968, the City of Windhoek in Namibia has pioneered direct potable reuse with the commissioning of the Goreangab Water Reclamation Plant. The history of this project, and ongoing developments, have been written about intermittently by a number of authors including Haarhoff and Van der Merwe (1996), du Pisani (2006), Lahnsteiner and Lempert (2007), Van der Merwe *et al.* (2008), du Pisani and Menge (2013), van Rensburg (2016) and Lahnsteiner *et al.* (2018).

Namibia is located in the south-western part of Africa and is the most arid country south of the Sahara Desert. Windhoek is the capital and largest city in Namibia, located in the centre of the country. The city is situated on the Khomas Highland plateau, at around 1,700 m above sea level. This arid location is 300 km from

the ocean and 700 km from the nearest perennial river. It has an annual average rainfall of 370 mm per year, almost all of which occurs in the six months of December to May. The population of Windhoek is around 400,000 and continues to grow due to migration from other parts of Namibia.

Historically, Windhoek had relied on groundwater to supply the city's needs. Since the 1930s two small surface water reservoirs were created by damming ephemeral rivers. The second of these was Goreangab Dam, constructed in 1958. A conventional water treatment plant was also constructed to treat the water to potable standards (du Pisani, 2006). However, the water supply to the Goreangab Water Treatment Plant was found to be limited and unreliable.

In 1968, the Goreangab water treatment plant was converted to treat wastewater from the city's Gammams WWTP as an additional source to the Goreangab Dam. The plant was thus renamed the Goreangab Water Reclamation Plant, treating municipal wastewater blended with raw surface water, with an initial capacity of around 4 ML/day. Because the whole city, including its extensive informal settlements, lies within the catchment area of the Goreangab Dam, the water from the reservoir is said to be often of lower quality than the municipal wastewater. The initial Goreangab Water Reclamation Plant, now called the "Old" Goreangab Water Reclamation Plant, was upgraded several times with the last upgrade undertaken in 1997 and an ultimate capacity of around 7 ML/day.

During eight years of water shortages between 1968 and 2000, the Old Goreangab Water Reclamation Plant produced at least 12% of the total potable water supply to Windhoek, with production peaking in 1997 with 18% (3 GL/year) of the total demand.

During the early 1990s, it was determined that additional capacity and improved water quality would be required in the future. A new plant, known as the New Goreangab Water Reclamation Plant (NGWRP) was then completed in 2002, on a site adjacent to the old plant. The NGWRP has a capacity of around 8 GL/year, and is approved to provide up to 35% of the total water supply on an ongoing basis and up to 50% during severe drought conditions. The City of Windhoek owns the plant, but its operations are contracted out to the Windhoek Goreangab Operating Company, an international private partnership company. The 20-year contract is managed through a private management agreement.

The plant design philosophy of the NGWRP follows the multi-barrier concept. The treatment train consists of coagulation/flocculation, followed by dissolved air flotation and media filtration. The water is subsequently treated by ozone/hydrogen peroxide followed by BAC filtration. A final barrier is provided by ultrafiltration prior to final stabilisation and chlorine disinfection. A simplified process flow diagram for the NGWRP is provided in Figure 8.

The concept of source control was also incorporated into the Goreangab project by collecting and treating industrial sewage separately for irrigation reuse (Van der Merwe *et al.*, 2008). To achieve this, a new industrial township was established to the north of the city and outside of the existing WWTP drainage area. Thus, predominantly municipal and commercial wastewater is used to augment the potable water supply.

Since 2018 a variety of water supply options including expansion of the capacity of the Gammams WWTP, which provides source water to the NGWRP, have been under consideration. The existing plant is based on a nutrient-removal activated sludge process and the expansion will be based on a parallel membrane bioreactor (MBR) process train. The City of Windhoek has engaged consulting services for the development of an advanced treatment drinking water plant at Gammams to follow the new MBR train. Consequently, it is anticipated that potable water reuse will be an increasingly important component of overall drinking water supply in the near future. As such, it is likely that the city will need to reconsider the currently imposed limit of 35% treated wastewater in the potable water blend.

10.6 Beaufort West Water Reclamation Plant, South Africa

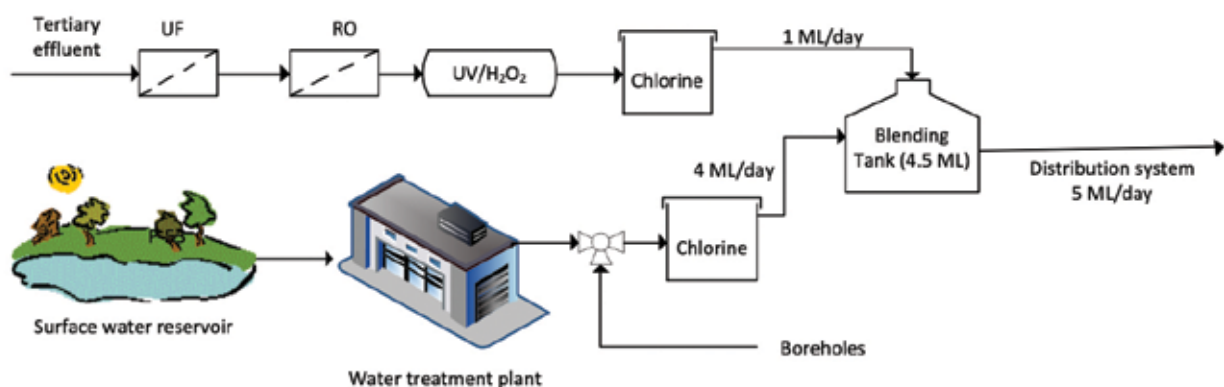
Beaufort West Municipality is situated in central Karoo, approximately 500 km north-east of Cape Town. It is one of the driest areas in South Africa, with an annual average rainfall of about 160 mm. Beaufort West Municipality functions as the economic, political and administrative centre of central Karoo. There are roughly 40,000 inhabitants in Beaufort West Municipality spread across three towns, one of which is Beaufort West.

In 2010, a severe drought nearly depleted the town's raw water sources, resulting in an immediate shortage of drinking water. By 2011, the town was relying on trucks delivering additional drinking water to support its inhabitants. At that time, five litres of drinking water per person per day were being trucked to over 8,000 homes. Frequent droughts in combination with predicted population growth and large informal housing areas that are yet to be connected to the water supply system are expected to increase the pressure on raw water sources in future.

The situation in Beaufort West led to the construction of a direct potable reuse plant known as the Beaufort West Water Reclamation Plant (BWWRP). The plant was constructed as a 'design, build and operate' project with local contracting firm 'Water & Wastewater Engineering' (Marais & von Durckheim, 2012). It was commissioned in 2011 and has been providing drinking water since. The product water quality exceeds the national standard for potable water (Burgess, 2015).

Subsequent to conventional tertiary treatment, the additional treatment processes used at the BWWRP include UF, RO, UV/H₂O₂ advanced oxidation and final chlorination. The plant is designed for a capacity of 2.1 ML/day. The recycled water is pumped to a 4.5 ML service reservoir 4 km away at a relative elevation of 100 m. The Municipality has three service reservoirs on the hill. The treated recycled water is fed into 'Reservoir 1'. The Municipality feeds conventionally sourced water (conventionally treated dam water and borehole water) to 'Reservoir 3'. In both instances the water is required to comply with potable water standards. The Municipality then blends approximately 20% recycled water and 80% conventionally sourced water into 'Reservoir 2'. This mixed water is then distributed to the town. Residual chlorine adjustment is provided as the water leaves Reservoir 2 to supply the town. A process flow diagram for the project is provided in Figure 9.

Figure 9: Process flow diagram of the Beaufort West DPR Project.



The same contractor that constructed the plant is also responsible for the daily operation and maintenance work over a 20-year contract period. It is intended that the blending ratio will be increased to 25% when the water reclamation plant is operating at full capacity.

10.7 'NEWater', Singapore

Singapore is a densely populated island city-state with few natural freshwater resources to draw from. A water sharing arrangement with neighbouring Malaysia has been a source of political tensions since Singapore was granted independence from Malaysia in 1965 (Chakraborti & Chakraborty, 2018). Consequently, the development of new water resources, including urban stormwater reuse and seawater desalination has been a consistently high priority for Singapore governments.

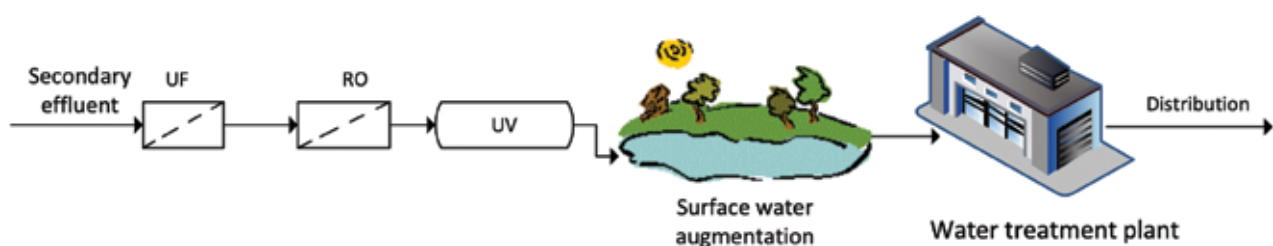
Singapore began practising surface water augmentation for potable reuse in 2003 with construction of two AWTPs at Bedok and Kranji. Since then, additional plants were constructed at Seletar in 2004 (decommissioned in 2011, in line with the Urban Redevelopment Authority Master Plan for land use), Ulu Pandan in 2007 and Changi in 2010.

The Singapore Public Utilities Board (PUB) has branded the recycled water produced from these plants as 'NEWater'. The treatment train employed at each of them is based on micro- or ultra-filtration, reverse osmosis and UV disinfection (Figure 10).

Since NEWater has ultralow dissolved salt concentration, it is ideal for processes that require high purity water. Thus NEWater is primarily supplied to Singapore's industrial sector such as to silicon wafer fabrication plants and to commercial buildings for industrial air-cooling purposes. It is also supplied to electronics and power generation industries.

During dry periods, some 110 ML/day of NEWater are used to replenish surface water reservoirs prior to conventional drinking water treatment with an annual average of 30 to 40 ML/day. Together, Singapore's four NEWater plants can meet approximately 30% of the nation's (potable and non-potable) water needs. By 2060, Singapore PUB plans to expand capacity so that NEWater can meet up to 55% of projected future demand.

Figure 10: Process flow diagram for NEWater potable reuse in Singapore.



Singapore's success with water reuse has been well documented and much discussed in the global water community, most notably in the area of securing public acceptance through a comprehensive and wide-ranging public communications programme targeting various groups of stakeholders (Lee & Tan, 2016). A key focus was engaging all stakeholder groups early in the process with relevant information. This included political leaders, media, grassroots organisations, business associations and religious groups. To build public trust and confidence, exhibitions and roadshows were also held at the school and community level.

A central aspect of the public education strategy was the establishment of the NEWater Visitor Centre, a very modern and high-tech water museum that acts as a centre for information regarding how NEWater is produced and the part it plays in Singapore's water strategy. The centre allows visitors to view the treatment process at the Bedok NEWater factory from a gallery and understand the science behind it through interactive displays, tours and workshops. The centre is open to community groups, individuals and foreign visitors. It has also become part of Singapore's National Education Programme, with regular visits from school groups. Singapore aims to have every child visit the facility during their primary school education. Allowing the public greater access to the 'nuts and bolts' of water reclamation has fostered trust and a sense of assurance (WHO 2017).

Singapore PUB promotes its management philosophy through the Four National Taps of Singapore program (Irvine *et al.*, 2014). The four national taps are: water from local catchment areas (urban stormwater); imported water (from Malaysia); desalinated water and NEWater. Recent research indicates that 74% of Singaporeans generally approve of NEWater (Timm & Deal, 2018). NEWater has won several awards for communication and education, including the "Water for Life" United Nations Water (UN-Water) Best Practices Award in 2014.

10.8 The Torreele/St-André facility in Wulpen, Belgium

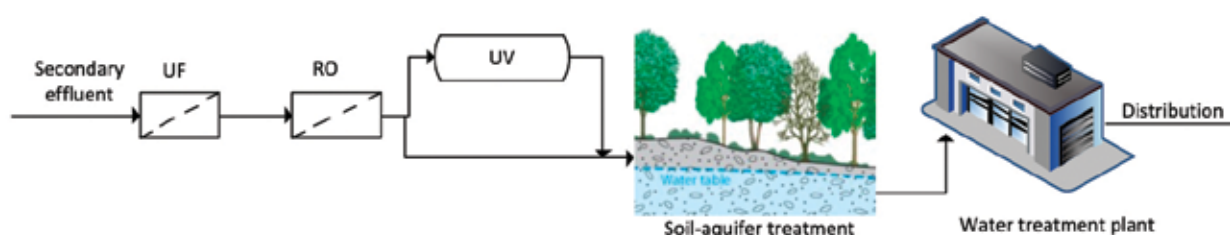
In the western part of Belgium's Flemish coast, groundwater is pumped from the unconfined St-André aquifer for drinking water supply by the Intermunicipal Water Company of Veurne-Ambacht (IWVA). However, in the 1990s, rapidly growing water demand had produced an overdraft on the aquifer. The groundwater level was dropping and there were growing concerns regarding the potential for saline intrusion to the aquifer.

The IWVA developed a plan to artificially recharge the aquifer using recycled water from the Torreele WWTP in Wulpen (Van Houtte & Verbauwheide, 2013). In 2002, the Torreele facility was upgraded for water reclamation, further treating the secondary wastewater by advanced treatment using ultrafiltration and reverse osmosis (Van Houtte & Verbauwheide, 2013). An extra treatment with a UV disinfection system is possible as backup disinfection unit when needed.

Membrane waste concentrate streams are combined with the portion of the treated wastewater that is not recycled and discharged to a nearby brackish canal. The recycled water is recharged to the aquifer via an infiltration pond in the dunes of St-André (Van Houtte & Verbauwheide, 2012) (Figure 11). The average residence time in the aquifer is around 55 days (Vandenbohede *et al.*, 2008).

The recovered water is conveyed to the potable water production facility at St-André which consists of aeration, rapid sand filtration, storage, and UV disinfection prior to distribution. Note that chlorine disinfection is not routinely used, but chlorine can be dosed when needed to prevent regrowth and recontamination in the distribution network.

Figure 11: Process flow diagram for the Torreele/St-André facility in Wulpen, Belgium.



The sewer network that delivers source water to the Torreele system is a 'combined' sewage system, conveying both municipal wastewater and urban stormwater. Consequently, meteorological and seasonal variations present major operational challenges to the facility (Van Houtte & Verbauwhede, 2012). Since the project started, 35 to 40% of IWVA's annual drinking water demand has been met by the combined of reuse/recharge system.

10.9 Western Corridor Recycled Water Scheme (WCRWS), QLD, Australia

A very large potable reuse project was constructed in South East Queensland, with the intention of augmenting surface water supplies for the area, including Brisbane (Traves *et al.*, 2008). The Western Corridor Recycled Water Scheme (WCRWS) was designed in 2007 to use the vast majority of treated municipal wastewater produced in South East Queensland, collected from six WWTPs at Bundamba, Goodna, Oxley, Wacol, Luggage Point and Gibson Island (Walker *et al.*, 2007).

This treated wastewater was planned to be delivered to three AWTPs at Bundamba (60 ML/day), Luggage Point (70 ML/

day) and Gibson Island (100 ML/day), where it would undergo advanced treatment by microfiltration, RO, UV-advanced oxidation and chlorine disinfection. Prior to construction of these three full-scale plants, smaller pilots were developed at two of the sites (Luggage Point and Gibson Island) to aid in process selection and test performance. The full-scale project was designed to produce a total recycled water supply capacity of 230 ML/day (Poussade *et al.*, 2009).

The AWTPs were interconnected into an overall system with extensive pipelines connecting the three plants and delivering the recycled water for intended reuse applications. They produced water for potable substitution to supply two nearby coal fired power stations, with a sizeable volume apportioned for potable reuse by augmentation of the region's largest surface water reservoir, Lake Wivenhoe. However, shortly following construction in 2009, drought breaking rains reduced the immediate water shortage. While water continued to be produced for industrial use, the Queensland Premier announced that this additional water supply would no longer be needed for potable supply, as long as South East Queensland water storages remained at above 40% of their capacity. That trigger has not been approached during the decade since passed. The proposed potable reuse scenario is presented in Figure 12.

Figure 12: Process flow diagram for the Western Corridor Recycled Water Scheme (WCRWS), Brisbane.

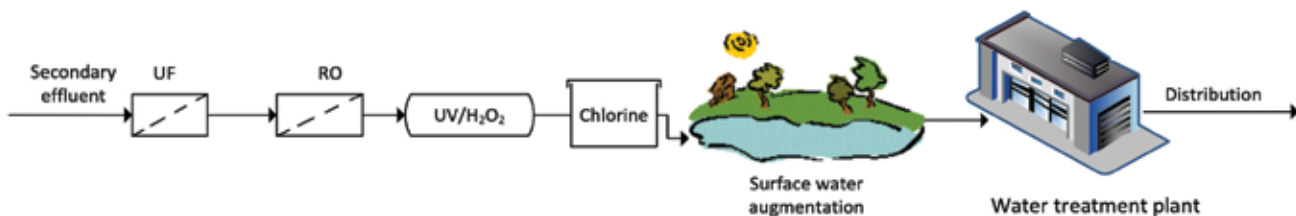
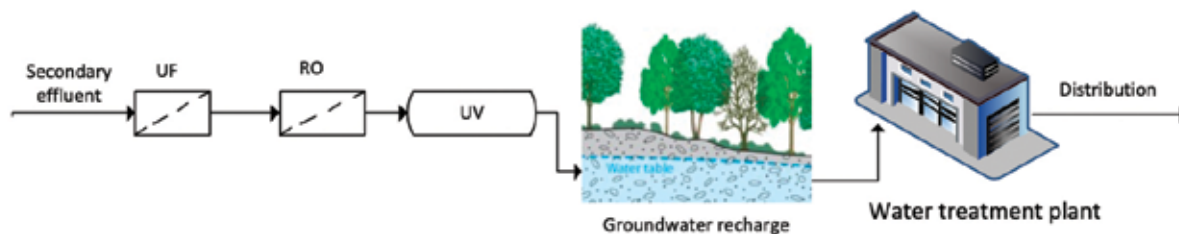


Figure 13: Process flow diagram for the Groundwater Replenishment Scheme (GWRS), Perth.



Comprehensive validation and verification testing during piloting and start-up of the facilities has been conducted (Roux *et al.*, 2010). These activities demonstrated that the recycled water quality meets, and even exceeds, the requirements of the Australian Guidelines for Water Recycling (NRMMC, EPHC & NHMRC 2008) as well as the Australian Drinking Water Guidelines (NHMRC & NRMMC 2011).

Validation for the Bundamba AWTP included more than 48,000 water quality results from samples collected during 2008-2010, as well as continuous online monitoring of key parameters during that period (WaterSecure, 2010). Following this process, the Chair of the Expert Panel appointed to oversee the public safety of the IPR project, Professor Paul Greenfield, reported to the Queensland State Government that “the test results in combination with continuous online monitoring have shown the treatment barriers are effective in producing water suitable for release to Wivenhoe Dam. The Expert Panel considered the four exceedances detailed in the report and determined that all exceedances constituted no health risk and would be more properly considered as early warning that corrective action should be undertaken” (Greenfield, 2010).

During this validation period, the AWTPs were also subject to further scientific research, including an assessment of the application of bioanalytical tools as surrogate measure of chemical contaminants in recycled water (Leusch *et al.*, 2014b).

Due to uncertainties relating to methods for validation of the environmental buffer performance, the full scheme performance requirements and validation were applied at the AWTPs. That is, it was necessary to demonstrate that the engineered processes could meet the required quality standards without any assumed contribution from the environmental buffer. As such, any additional treatment benefit from environmental buffer is assumed to provide an unquantified level of ‘treatment redundancy’, implying an additional level of safety were the engineered treatment processes to fail or underperform.

Modelling undertaken in 2012 indicated that there was only a five per cent cumulative chance of the WCRWS being fully required by 2030 (Queensland Audit Office, 2012). The WCRWS ceased supply of water to the power stations at the end of 2013 and was placed in to ‘care and maintenance’ in 2015. Doing so was proposed to limit the annual increase on bulk water charges and therefore produce savings for household water customers. The scheme can be restarted when required as one of South East Queensland’s drought response measures, assisting with long-term water security for the region.

In 2017, Seqwater produced Version 2 of its “Water for Life: South East Queensland’s Water Security Program 2016-2046” (Seqwater, 2017). This document lays out a plan for how water supply security for the region will be maintained over the 30 year period. Among many diverse strategies, the WCRWS will start remobilisation if ever the combined South East Queensland key bulk water storages drop in volume to below 60% of their full capacity. The Restart Project involves the remobilisation and restart of the WCRWS to be delivering 180ML/day of recycled water to be available for augmentation of Lake Wivenhoe within two years from the restart trigger date.

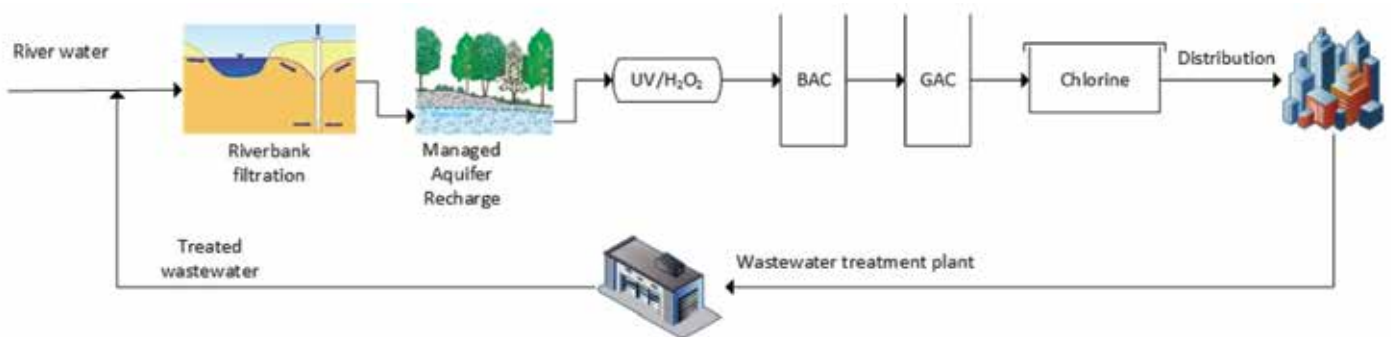
Once a restart is triggered, Seqwater intends to bring the WCRWS back on line one plant at a time starting with Luggage Point to allow for the full remobilisation to be halted in the event of rain filling dams. This progressive approach allows for:

- Early regulatory testing to assist and streamline the subsequent testing of the remaining scheme
- Operational condition of the assets to be ascertained as early as possible
- Recycled Water to be supplied to augment the supply into Wivenhoe Dam as early as possible
- Increasing scheme capacity during the two years
- The ability to adjust down if necessary the scheme restart capacity throughout the two-year period

10.10 Groundwater Replenishment Scheme (GWRS), Perth, WA, Australia

The only operating project identified as a “planned” potable reuse project in Australia is currently the Groundwater Replenishment Scheme (GWRS) operated by Water Corporation of Western Australia. Located in the northern suburbs of Perth, the GWRS is a managed aquifer recharge project, designed to recharge important drinking water aquifers for the city. Secondary-treated wastewater is sourced from the Beenyup WWTP and further purified at an adjacent AWTP by ultrafiltration, reverse osmosis and UV-disinfection. Recharge bores are used to deliver the recycled water to Yarragadee and Leederville aquifers. These aquifers provide a source of raw drinking water for Perth, which is then treated at conventional water treatment plants prior to municipal distribution (Figure 13).

Figure 14: Process flow diagram for the Prairie Waters Project, Aurora, Colorado.



Prior to commissioning, this project was preceded by an extensive groundwater replenishment trial (2010-2012), which also served as a basis for research, community information sharing, and for regulatory development with the relevant public health regulator, WA Department of Health. A 5 ML/day AWTP was constructed for the trial and the performance of this plant was validated during 2009 and 2010. The treated water produced by the plant was used to recharge the Leederville aquifer by direct injection throughout the three-year trial (Water Corporation, 2013). This water was recharged into the aquifer 120 to 220 m underground, at a location remote from any drinking water abstraction wells.

Following the successful completion of the Groundwater Replenishment Trial, the Western Australian Government announced that groundwater replenishment would become the next climate independent water source to secure Perth’s drinking water supply (Redman, 2013). Stage 1 of the full-scale GWRS was constructed and commenced operations in 2017. This first stage has the capacity to recharge the Leederville and Yarragadee aquifers with up to 14 GL/year of purified water.

The development of Stage 2 of the GWRS is currently underway with the construction of a second full-scale AWTP as well as construction of new recharge bores and associated recharge pipeline to the north-east of the Beenyup plant in Craigie. This second stage is expected to be completed during 2019 and will produce a doubling of the scheme’s capacity to 28 GL/year. Water from Stage 2 will be recharged into the confined Leederville and Yarragadee aquifers via two recharge sites, one in Wanneroo and one in Neerabup. It is proposed that by 2060, groundwater replenishment could recycle 115 GL/year with water sourced from a number of WWTPs.

As a pioneering potable reuse project in Australia, the GWRS has contributed to much important research, including around the ability of the advanced treatment processes to produce highly treated wastewater (Busetti *et al*, 2015). A carbon footprint assessment of the GWRS (but based on the smaller plant used during the trial project) revealed potentially significant greenhouse gas emissions savings for this approach to potable reuse, compared to seawater desalination (Simms *et al*, 2017). This is of interest since seawater desalination is currently an important water supply strategy for Perth and a number of other Australian cities.

10.11 Prairie Waters Project, Aurora, Colorado, USA

The Prairie Waters Project in Aurora, Colorado provides another example of the diverse approaches that may be adopted for potable reuse. In this case, source water is taken, not directly from a WWTP, but from the South Platte River, downstream from the Denver Metro Wastewater Reclamation District’s WWTP.

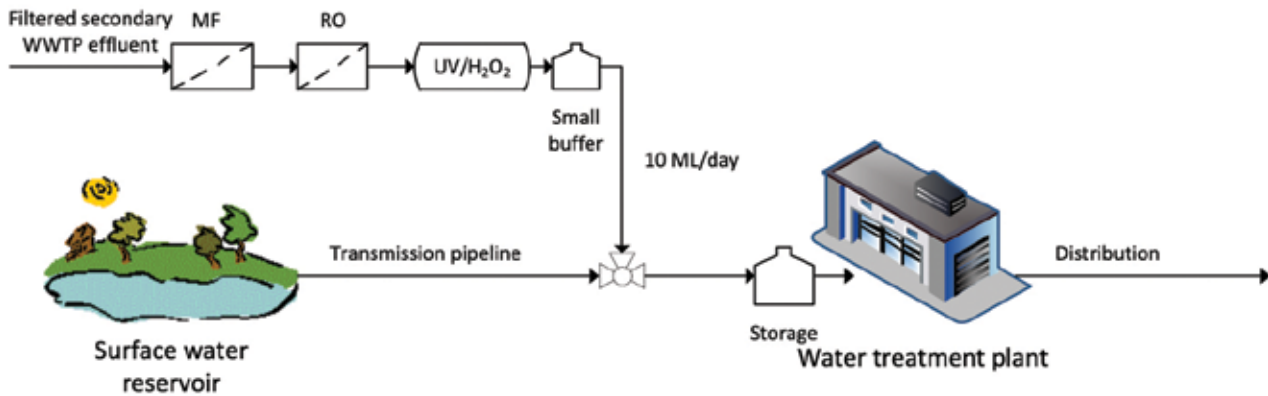
The city of Aurora has limited availability of fresh water resources from which it can draw. However, it owns water rights in the South Platte River Basin. The net quantities of water than can legally be extracted are finite, but in most cases, Aurora’s water rights allow the city to use the water “to extinction”. That is, water which is returned to the river as treated municipal wastewater, may be recycled and reused without adding to the tally of legal water extractions. The Prairie Waters Project was conceived and constructed to capitalise on this opportunity (Aurora Water, 2016).

The first stage of the Prairie Waters Project involves recovering water from South Platte River, close to the city of Brighton. This water contains a high degree of wastewater discharge (>80%). As an initial purification step, a process of “riverbank filtration” was developed, as is relatively commonly used in some European cities, such as Berlin and Mainz. During this process, 23 extraction wells draw the water through a distance of sand and gravel river bank. A subsequent process of soil aquifer recharge is applied, whereby the water is pumped into infiltration basins where it percolates through more sand and gravel over a longer period of time, effectively extending the riverbank filtration process.

The recovered water is then pumped, via a 60 km pipeline back upstream of Aurora to the 190 ML/day Peter Binney Water Purification Facility, adjacent to the Aurora Reservoir. Pumping stations lift the water almost 300 m on this journey.

Advanced water treatment at the Peter Binney Facility consists of partial softening, UV/H₂O₂ advanced oxidation, BAC filtration, and final GAC filtration (Figure 14). Subsequently, the water is blended in a ratio of 1:2 with Aurora’s current supply (mountain run-off after conventional surface water treatment), disinfected with chlorine and delivered to the city’s distribution system.

Figure 15: Process flow diagram of the Big Spring DPR scheme.



Development of the Prairie Waters Project was initiated in 2007 and it was completed in 2010. The main motivation for selecting the advanced treatment processes was the desired removal of chemicals of emerging concern and pathogens to deliver a water quality that was indistinguishable to Aurora’s current supply.

Based on experience in California, in particular the GWRS in Orange County, a UV/ H₂O₂ process was selected in 2005. The principal driver for selecting UV/H₂O₂ was NDMA removal efficiency and pathogen inactivation credits using UV. After construction of the facility had started, studies at the site demonstrated that NDMA and other nitrosamines were efficiently removed during the natural treatment process (riverbank filtration followed by artificial recharge and recovery) (Drewes *et al.*, 2006) and concentrations of NDMA at the influent of the advanced oxidation process were consistently below detection levels (<10 ng/L).

10.12 Raw Water Production Facility, Big Spring, Texas

Big Spring is a city in West Texas, USA. It is located in the Permian Basin, with a population of approximately 30,000 people. The Permian Basin has been subjected to severe drought conditions during much of the last 15 years. Water supply servicing to Big Spring is provided by the Colorado River Municipal Water District (CRMWD). Most of the water supplied is raw surface water from three reservoirs constructed on the Colorado River. These sources are supplemented by groundwater reserves, but in the early 2000s it was apparent that additional supplies would be needed to meet growing demand and to offset apparent reductions in reservoir yields.

The Big Spring WWTP is located east of Big Spring, and is permitted to treat up to 14 ML/day of municipal wastewater. It was identified that The Big Spring WWTP effluent could be used in several ways to augment or offset potable water demand in Texas. The principal categories considered included direct non-potable irrigation, direct non-potable industrial use, as well as both IPR and DPR (Sloan & Dhanapal, 2007). Several factors persuaded the CRMWD to pursue potable reuse, including (Sloan, 2011):

- Non-potable reuse demands tend to be highly seasonal, limiting the overall volume saved from reuse facilities. Potable reuse represents a continuous demand.

- Few large potential customers were available for non-potable reuse.
- Low-density development in the area meant that transmission distances for distributed non-potable reuse would be significant and distribution systems expensive.
- Arid conditions have restricted landscape irrigation, reducing potential demand.
- High concentrations of dissolved solids in the wastewater limited reuse opportunities unless desalination (reverse osmosis) was included.
- Current raw drinking water sources and other prospective sources are generally distant and lower in elevation than customers, resulting in high delivery costs, while recycled water is already local.

It was recognised that blending recycled water with raw drinking water offered the opportunity for year-round use, reduced transmission distance and an improvement in raw water salinity. Several locations in Texas have developed plans for indirect potable reuse. However, IPR was not considered to be as well suited to the Permian Basin area, due to high evaporative losses and the salt concentrations in both the current surface water and in available wastewater sources.

Salt removal by reverse osmosis was deemed a necessary step for large-scale water reclamation. With this level of treatment came the opportunity to shorten the reuse cycle. The CRMWD’s network of long-distance, large diameter pipelines presented a convenient means of blending high-quality recycled water with other sources and conveying the blended product to their customer cities.

The implemented DPR project intercepts filtered secondary wastewater from the Big Spring WWTP and transfers it to an adjacent site, where advanced treatment is provided. The AWTPs consist of microfiltration, reverse osmosis and UV/H₂O₂ advanced oxidation, with capacity to produce up to 7 ML/day. This water is then blended with raw surface water in the CRMWD’s water transmission pipeline as shown in Figure 15. Project construction began in June 2011, with blending operations having begun in April 2013. This facility is now known as the Big Spring “Raw Water Production Facility” (RWPF), emphasising its role in providing additional source water for the existing drinking water filtration plant.

The RWPF was permitted based on the inclusion of the three barriers MF, RO, and UV/AOP (Steinle-Darling *et al.*, 2016). An initial assessment revealed that the main pathogens of concern were viruses and the Texas Commission on Environmental Quality (TCEQ) required the UV/AOP system to achieve a minimum 4 LRV for viruses to supplement the existing 4 LRV credited to each of the downstream surface water treatment plants, for a total of 8 LRV for viruses. For protozoa, the TCEQ credits 4 LRV to the MF and 6 LRV to the two UV reactors in series, for a total of 10 LRV at the RWPF, plus 3 LRV at the downstream conventional surface water treatment plants, for a sum total of 13 LRV for *Cryptosporidium* and *Giardia*.

The Big Spring RWPF now contributes up to 15% of the blended water in the existing pipeline network supplying CRMWD's member and customer cities including Big Spring. These cities operate conventional surface water plants which will continue to provide final treatment, including disinfection, prior to drinking water distribution to customers.

The advanced treatment processes used in this reclamation project require significant energy to produce a high quality product suitable for blending. However, the designers of this project have considered this in the context of the energy requirements of existing supplies and other potential supplies (Sloan, 2011). It was estimated that the MF and RO treatment will use around 13 kWh of energy per 1000 litres of water produced (13 kWh/kL). UV oxidation was estimated to require an additional 1.5 kWh/kL and pumping to and from the reclamation facility would increase the total to around 20 kWh/kL recycled water.

By comparison, lifting water from the existing reservoir (Lake Spence) to Big Spring requires about 16 kWh/kL under normal conditions. On some occasions, the water level in the reservoir is so low that a barge mounted pump station has been required to lift water into the permanent intake structure. The power consumption for the barge operation is not readily available, but it is apparent that lifting water to Big Spring requires almost as much energy as treating and pumping wastewater from the WWTP (Sloan, 2011). The CRMWD currently uses about 3 kWh/kL to pump wastewater from the WWTP, away from the Colorado River, to protect drinking water supplies. Each litre recycled therefore represents a litre of avoided wastewater pumping. Adding this to the normal raw water pumping requirement from Lake Spence yields a total of 19 kWh/kL of avoided energy, comparable to the energy requirement for the total reclamation process.

In terms of engineered storage buffers, the RWPF includes about 2 ML of product water storage, which represents 6-7 hours at full production. After blending and prior to potable water treatment, the water is transferred to a 60 ML balancing reservoir. This is an

open, earthen reservoir, which was constructed to allow mixing and equalisation for a number of raw water sources at a strategic junction in the system. It was in place long before the reclamation project was conceived, and although it does represent storage and potential delay before proceeding to final treatment and distribution, it is not monitored or controlled for that purpose. There also are no test results which are required to allow the recycled water to be released. The CRMWD relies upon continuous filtrate turbidity and RO permeate conductivity to confirm the quality of the treated water, supplemented by air pressure tests of the membrane filtration and continuous monitoring of the UV disinfection system.

10.13 Ongoing development of new potable reuse projects in the USA

During the last decade, there has been rapid acceleration in interest for DPR projects in the USA. Following the success of projects such as the Raw Water Production Facility in Big Spring, Texas, a number of others are now in an advanced planning stage. These include DPR projects in San Francisco (California), Ventura (California) and El Paso (Texas).

10.13.1 San Diego, California

Around 85% of the water supply used by the City of San Diego is currently imported from distant sources, including the California Bay-Delta between San Francisco and Sacramento, and the Colorado River, conveyed over large distances via piped aqueducts (Steirer & Thorsen, 2013).

Both of these major import sources are increasingly subjected to restrictions, which has forced the city to examine other options for water supply. The privately owned Carlsbad desalination plant, which began operation in 2015, and another at Huntington Beach, to open in 2019, will provide some of the answer. Yet, faced with rapid population growth, the city has recognised that these plants will not be sufficient to sustain ongoing needs.

In addition to its water supply needs and the cost of buying imported water, the city was facing a crucial date in 2015, by which it would need to renew its National Pollutant Discharge Elimination System (NPDES) permit for the Point Loma WWTP. This placed significant pressure on the city to identify wastewater reuse opportunities, which would drastically reduce the need for ocean outfall disposal.

In exploring the opportunities and feasibility for a potable reuse project, the city established the San Diego Water Purification Demonstration Project during 2009 to 2013 (Wetterau *et al.*, 2013).

The key aspect of that project was the construction and operation of a 4 ML/day demonstration/pilot plant known as the 'Advanced Water Purification Facility' (Steirer & Thorsen, 2013).

In 2014, the San Diego city council voted unanimously for a plan to construct a full-scale potable water recycling project to recycle over 110 ML/day by 2023 (Phase 1) and over 310 ML/day by 2035 (Phases 2 and 3). This project has been branded 'Pure Water San Diego' and is expected to provide third of San Diego's water supply when complete.

Construction of Phase 1, to supply the North city areas of San Diego will start in 2019. An advanced water treatment facility will supply recycled water, which will be piped to the Lake Miramar in the northern suburbs of San Diego. Miramar is a small lake, largely surrounded by urban development, which is used as a holding reservoir for San Diego's imported water sources, prior to treatment at the adjacent Miramar Water Treatment Plant, and distribution to customers.

This project is considered to be an IPR project and the Pure Water Program will become a model for the application of potable reuse by surface water augmentation in California, following the recent update California's Title 22 Code of Regulations to facilitate this (see Section 5.1.1).

In planning for Phase 1, it was initially considered to send the recycled water to the much larger San Vicente Reservoir. However, that would have required a pipeline of 45 km from the North city Pure Water Facility, instead of 13 km to Lake Miramar.

Phases 2 and 3 will involve the development of two additional advanced water treatment plants, one to serve the Central Area of San Diego and the other in the southern region, known as South Bay. Water from the Central Area plant will be piped to the small, urban Lake Murray, and some possibly on to the larger and more distant San Vicente reservoir. Water from the South Bay plant will be piped to the Lower Otway reservoir. Plans for Phases 2 and 3 may evolve over time and may be impacted by the establishment of Californian criteria for DPR through raw water augmentation, due before the end of 2023.

Despite the completion of the San Diego Water Purification Demonstration Project, the 'Advanced Water Purification Facility' has continued to operate (Steirer & Thorsen, 2013). The plant has been used for public outreach activities and to test alternative treatment processes and monitoring techniques that could provide additional health and safety barrier options for direct potable reuse projects. Recent work has included the evaluation of mechanical reliability of treatment processes used for potable reuse applications (Pecson *et al.*, 2018).

10.13.2 Ventura, California

The City of Ventura in California's Central Coast relies entirely on local water supplies. Unlike nearby Southern Californian cities (Los Angeles and San Diego), Ventura does not have access to imported water supplies. Ventura's drinking water is sourced from the Ventura River, Lake Casitas, and local groundwater basins. In times of minimal rainfall and drought, water levels drop and these supplies become limited.

The City of Ventura currently provides recycled water from the Ventura Water Reclamation Facility to two golf courses and landscape irrigation in the Harbor and Olivias Drive areas. Ventura Water has been investigating options for additional water reuse for many years. The findings of these studies have shown that potable reuse has the largest benefit for the city. Other options evaluated included providing highly treated water to local agriculture or to recharge basins, but these options were found to not directly expand Ventura's water supply.

Ventura Water Pure, the city's new Potable Reuse project, has been developed with a plan to increase Ventura's drinking water supply and help to sustain the city's existing water resources. The project has included the construction of the VenturaWaterPure demonstration facility, providing treatment to recycled water by microfiltration, reverse osmosis and UV/H₂O₂ advanced oxidation. This facility was opened in 2015 with intention to demonstrate capacity to produce water for direct potable reuse (DPR).

It is proposed that following advanced treatment, recycled water produced by a future full-scale plant will be sent to the local drinking water treatment plant and mixed with water from Lake Casitas, the Ventura River, and local groundwater supplies before it is sent to homes and businesses. Such an arrangement, if designed appropriately, would meet the recently adopted Californian State definition for "raw water augmentation" (See Section 5.1.2).

10.13.3 El Paso, Texas

El Paso, on the US-Mexico border in west Texas has a population of 700,000 and, by virtue of proximity, shares all local water resources with its sister city of Ciudad Juarez, Mexico. An essential local water resource has been groundwater from the Hueco Bolson aquifer. However, the Hueco Bolson has been subjected to a very large overdraft and reported to have dropped by 45 m between 1940 and 1999. Since then, El Paso has endured drought conditions for most of the two decades (Maseeh *et al.*, 2015).

In the 1980s, El Paso began treating wastewater for reuse by a number of applications including irrigation. Treated wastewater has also been used to recharge the Hueco Bolson aquifer by infiltration

through unlined ponds. However, this process incurs large evaporative losses. Since around 2013, the city has been planning for alternative means of potable reuse (Maseeh *et al.*, 2015).

In 2016, El Paso Water completed a pilot test for an advanced water treatment facility, which is intended to lead to the development of a full-scale DPR facility. The pilot facility was designed to purify secondary municipal wastewater by microfiltration, reverse osmosis, UV/H₂O₂ advanced oxidation, GAC filtration (for peroxide quenching), stabilisation and disinfection with free chlorine. Following the successful piloting, the Texas Commission on Environmental Quality gave El Paso Water approval to proceed with design of the full-scale facility.

El Paso Water is currently designing the Advanced Water Purification Facility, which will produce up to 38 ML/day of water, to supplement the city's drinking water supplies. Unlike other potable reuse facilities in the United States, which return drinking water to a treatment plant or blend with other raw water sources, the Advanced Water Purification Facility will use a direct-to-distribution approach, with the recycled water flowing directly into the drinking water distribution system.

Water Research Australia Limited

ACN 127 974 261

Level 2, 250 Victoria Square, Adelaide SA 5000

GPO BOX 1751, Adelaide SA 5001

+61 8 7424 2445

info@waterra.com.au

waterra.com.au

