MANAGED AQUIFER RECHARGE

THE CASE OF GROUNDWATER REPLENISHMENT SCHEME (GWRS) FOR POTABLE REUSE IN PERTH, WESTERN AUSTRALIA

Infrastructure innovation and policy assessment

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OVERVIEW OF THE GROUNDWATER REPLENISHMENT SCHEME (GWRS)

Groundwater is formed from 'rain or melting ice or snow' found in the pores between 'rock and sediment' under the Earth's surface and is stored in aquifers which are underground formations of gravel, sand, or limestone. It is typically pumped from aquifers and used for multiple purposes including drinking water [1–3]. As water demands increase, there is a risk of groundwater depleting overtime. Consequently, innovations like Managed Aquifer Recharge (MAR) intend to ensure the availability and sustainability of water supplies [4,5].

The Groundwater Replenishment Scheme (GWRS) in Perth, Western Australia is a MAR implementation introduced by the State-owned Water Corporation [6]. Water from this scheme currently forms 3% of the State's Integrated Water Supply Scheme which also comprises desalinated water, groundwater and dams [7,8]. Groundwater replenishment begins by recycling wastewater from domestic use like showers and laundry and ends by replenishing or recharging the deep Leederville and Yarragadee aquifers with purified water.

Wastewater from residences is collected through a network of wastewater pipes and pumped into the Beenyup Wastewater Treatment Plant (one of three largest treatment plants in Western Australia) to undergo a three-stage treatment process. Preliminary treatment involves the removal of large objects such as plastic through filter screens. Next, the wastewater is passed through 'grit removal tanks' to separate out heavy inorganic substances like rocks. The settled water is then drained and subsequently transferred to sedimentation tanks for primary treatment. During this stage, any particles present in the water sink to the bottom to form sludge which is pumped out to a separate treatment area. Although the water is quite clear at this stage, it still contains organic material that needs to be flushed out. The final stage entails removing this organic matter and it is achieved by pumping air into the tanks retaining the water to activate naturally occurring microbes (e.g. bacteria). Aerating the water provides microbes with oxygen necessary for removing residual contaminants and decomposing organic matter into carbon dioxide and other by-products. Once this stage is completed, the water is moved to secondary sedimentation tanks where it is either discharged to the ocean or transferred to advanced water recycling plants for further treatment [9,10].

Treated water from the Beenyup Wastewater Treatment Plant undergoes a three-step tertiary purification at the advanced wastewater treatment plant. Ultrafiltration screens out dissolved substances from the water. Next, the water goes through reverse osmosis which entails passing the water through tiny pores to further strip out smaller dissolved particles. Finally, the water is exposed to ultraviolet light to destroy any residual micro-organisms. At this point, the water is certified potable i.e. safe for drinking and is injected into the Leederville and Yarragadee aquifers for future retrieval [8,11].

With Western Australia experiencing lower annual rainfall volumes in recent years [12], the GWRS enables replenishment of groundwater without relying on natural sources like rainfall and snow. The GWRS is also less costly and up to 30% more energy efficient than the previously preferred seawater desalination option [6]. Finally, the innovative use of wastewater as groundwater recharge creates a reduced dependence on groundwater from surface sources like lakes or superficial aquifers which are less resilient to climate change effects [13].

IMPACT OF THE GROUNDWATER REPLENISHMENT SCHEME (GWRS) ON INFRASTRUCTURE PROVISION AND POLICY OUTCOMES

Since the 1970s, climate change and drought conditions have led to a steady decline in rainfall in Western Australia which has in turn impacted annual streamflow volumes. Between 1974 and 2019, streamflows into Perth's dams reduced from 420 billion litres to 44 billion litres [6]. It is also projected that

Western Australia would experience a 40% drop in annual rainfall by 2060 [14]. This is further complicated by a predicted annual supply gap of 70 billion litres before 2030 [15]. It is against this backdrop that the Water Corporation drafted the 50-year 'Water Forever: Towards Climate Resilience' plan in 2009, to set a pathway of safeguarding its water resources through climate-independent water sourcing options. One of such options considered was groundwater replenishment.

Prior to commencing the Groundwater Replenishment Scheme (GWRS) in Perth, the Water Corporation conducted a trial from November 2010 to December 2012 at the Beenyup Wastewater Treatment Plant (BWTP). As this was the first time executing a Groundwater Replenishment trial (GWRT) in Australia, there were no existing guidelines at the Federal or State levels to steer its implementation. Groundwater resources had also been historically protected by legislation, given Western Australian communities' heavy reliance on them for supply, thus presenting a possible complication to the planned GWRS [16]. Having anticipated these potential barriers when it first identified groundwater recharge as a possible water source, the Water Corporation began active stakeholder and community engagement in 2004 in advance of the GWRT [17].

The GWRT sought to determine the feasibility of the proposed GWRS, resolve public misconceptions about the safety of recycled wastewater and develop a regulatory framework that would guide future GWRS. Outcomes achieved during the trial include [13,17]:

- Development of the Groundwater Replenishment Regulatory Framework comprising applicable legislation and policies, roles and responsibilities of participating agencies, recycled water quality parameters and indicators, and water quality guidelines
- Successful demonstration of the treatment processes at the BWTP and purpose-built Advanced Water Treatment Plant (AWTP) to generate 2.5 billion litres of treated water
- Recharge of the Leederville aquifer (to a depth of 120 – 200metres) with treated water
- Community support of the trial and acceptance of GWRS expansion projects

In August 2013, the first phase of the GWRS was approved with the expansion of the BWTP commencing in 2014 [16]. Recharge of treated wastewater into assigned aquifers began in 2017 with a capacity of 14 billion litres of water per year. Extension of the GWRS facilities to double current production capacity started in 2019 and is billed for completion in 2021 [18]. A combined volume of 28 billion litres is expected to be generated annually via the upgraded GWRS which can supply up to 100,000 homes [19]. Given its potential to supply up to 115 billion litres per year by 2060, the GWRS thus creates a means of providing access to sustainable drinking water for Perth residents [14]. Furthermore, the detailed regulatory guidelines developed during the trial yielded a roadmap for the GWRS that ensures harms to human health and the environment are minimised [13].

INTEGRATION OF THE GROUNDWATER REPLENISHMENT SCHEME (GWRS) INTO EXISTING INFRASTRUCTURE SYSTEMS

Phase one of the GWRS started with expanding the Advanced Water Treatment Plant (AWTP) initially constructed for the GWR trial at the Beenyup Wastewater Treatment Plant (BWTP) site. Located in the northern Perth suburb of Craigie, the BWTP was selected based on advice from the Environmental Protection Authority (EPA), to site the scheme in an area that posed minimal risks to both human health and the environment. Given that there were no regulatory guidelines at the time of the trial, it was essential for the Water Corporation to adopt safety measures that would also be applied during the eventual GWRS. Accordingly, situating the GWRS at the remote BWTP site was to prevent unintentional contamination of drinking water supplies provided through existing infrastructure such as abstraction bores or wells, during the wastewater treatment process. In addition, this meant that the replenishment process would not interfere with existing water supply infrastructure, as the four recharge bores for feeding assigned aquifers with recycled treated water, were appropriately distanced from these [16].

A crucial element of the GWRS is its monitoring and control mechanism which ensures treated water satisfies the quality indicators developed during the trial. This mechanism comprises two aspects; first, Critical Control Points (CCP) which are set up at both the BWTP and AWTP to detect points of deviation during the treatment process where the water does not meet quality indicators. Whenever this happens in either treatment plant, the CCPs automatically trigger one of two possible remedial actions – divert the water from the process or halt the process altogether. This prevents untreated water from being introduced into the aquifer layers. Second, monitoring bores are installed within 50 and 100m of each recharge bore to serve as early warning systems. Recharge Management Zones (RMZ) are defined for each recharge bore at minimum radial distances of 250m to act as protective barriers between recharge sites and existing public drinking water extraction points. The RMZ along with the recharge and monitoring bores clusters preserves the environment including aquifers, from contaminants through quick detection of variations in quality metrics of treated wastewater [15]. This control mechanism is also being duplicated for the ongoing second phase of the GWRS. However, unlike phase 1, the recharge and monitoring bores would be installed at two offsite locations which would be connected to the BWTP via a 13km long pipeline [18].

In consultation with the State's Department of Water, the Water Corporation selected the Leederville and Yarragadee aquifers for both phases of the GWRS for their depth in relation to superficial/shallow aquifers. Both aquifers also help to create a buffer to counter the environmental effects of abstracting water from superficial aquifers [20]. In this way, the GWRS enables a means of securing groundwater supplies and sourcing climate-independent potable water, as the trial had established that it would take a minimum of 30 years for recycled water to be drawn out of the deep aquifers [21].

Financing for both phases of the GWRS was provided by the Western Australian Government as part of its \$3.6 billion[1] investment dedicated to augmenting water and wastewater infrastructure [22]. While the first phase cost \$125 million, the GWRS phase two amounts to \$262 million [23,24]. The Water Corporation's revenue is derived from supplying water, wastewater, drainage, and irrigation services to its customers. Residential customers pay variable water use and fixed service charges respectively. While water use charges are tiered, based on actual usage and calculated on a bimonthly basis, service charges represent service provision costs and are billed annually [25]. Given that groundwater replenishment is predicted to contribute 20% of Perth's drinking water source, and being less costly than seawater desalination, there is a possibility that water rates might be lowered in the coming years [13,26]. This may prolong recoverability of the State's water investments; a possibility that seems legitimate in light of the Economic Regulation Authority's call to review excessive water rates [27].

Maintenance and operation of Perth's water production, wastewater treatment and recycling facilities was initially contracted under an alliance agreement between the Water Corporation and two private companies, Suez Water Pty Ltd and Broadspectrum. The partnership, tagged Aroona Alliance, was formed in July 2012 and billed to run for a period of 10 years [28]. However, in 2019, the State Government announced that these services would be reverting to its control [29]. Citing annual cost savings and the ability to deliver 'better services for Western Australians', the State Premier also stated that absorbing this expertise into the Water Corporation would be valuable to the State in the long term. Likewise, the State Water Minister remarked that the Water Corporation would be resilient in responding to climate change effects. As at 2020, over 400 staff from both Aroona Alliance and other similar contract

[1] All quoted figures are in Australian dollars

arrangements in Western Australia had been absorbed into the Water Corporation [30]. Indeed, this move may prove beneficial to the long-term success of the GWRS given that the requisite skills for its continuous maintenance and operation appear to have been seamlessly integrated into the Water Corporation. Conversely, this implies that the State now bears the responsibility for the payroll costs of these personnel.

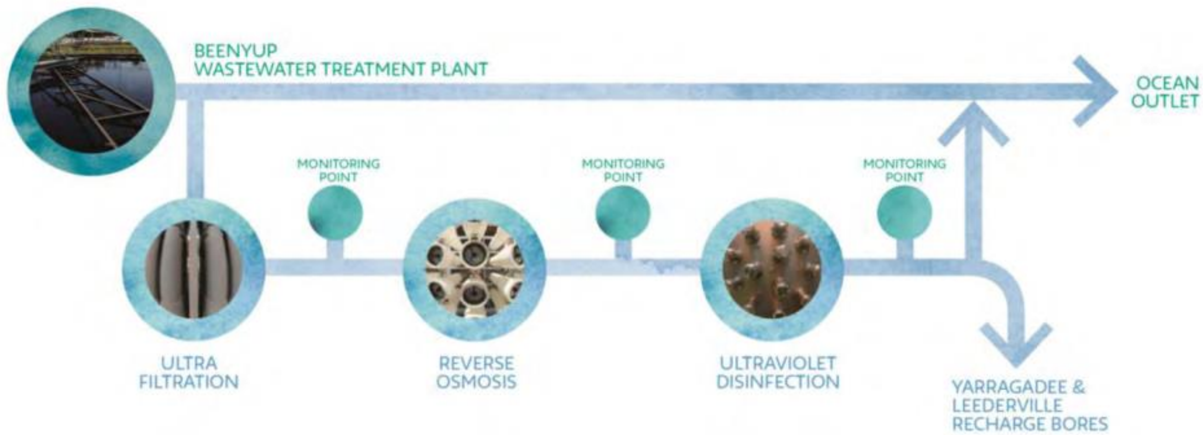

Figure 1: Overview of the three-stage advanced wastewater treatment process

OBSERVATIONS FROM THE GROUNDWATER REPLENISHMENT SCHEME (GWRS) IMPLEMENTATION

Several factors have contributed to the largely successful GWRS not least of which was the Water Corporation's astuteness in managing its end-to-end implementation. When the idea to explore groundwater replenishment as a climate-resilient means to future-proof water supply first developed in 2003, the Water Corporation established an internal water recycling team to commence preliminary research and engage regulatory stakeholders [16]. As it was the first of its sort in Australia, no policies or regulatory framework existed at both the State and Federal levels to which the Water Corporation could refer to. By 2005, the Water Corporation had secured State Government funding to conduct a three-year research in collaboration with the Departments of Health and Water, Curtin University, and Commonwealth Scientific and Industrial Research Organisation (CSIRO), among other institutions ahead of the GWR trial. This research sought to provide evidence that wastewater could be treated to a degree safe enough for recharging groundwater for subsequent potable use [31]. As a result, 254 water quality guidelines, 292 Recycled Water Quality Parameters (RWQP) and 18 Recycled Water Quality Indicators (RWQI) were identified against which recycled water would be assessed [17]. These would eventually form the basis of developing a regulatory framework for both the trial and subsequent groundwater replenishment scheme.

The Water Corporation was also quick to recognise potential barriers to implementing a GWRS in the form of opposition from community members, from whom 98% of wastewater is derived and treated at the Beenyup site [17]. Specifically, previous attempts by the Queensland government to implement a similar managed aquifer recharge scheme met with stiff community resistance which led to the government abandoning these plans. [32,33]. Learning from this experience, the Water Corporation drew up a communications strategy in 2004 to actively involve a broad range of stakeholders including community members, local Aboriginal groups, technical experts, and political leaders. The strategy, which was sustained for the duration of the trial, employed a variety of communication channels – physical meetings, print media, social media, online information portal and press briefings. Guided tours of the GWR site were also organised for community members as well as children. To this day, a Visitors Centre at the site receives ‘tourists’ while still serving as a way of retaining community support and acceptance of the scheme. Between October and December 2012, pre and post tour surveys conducted at the centre resulted in an increase of 74% to 93% in support of groundwater replenishment. These engagement efforts proved so rewarding that questions like ‘why don’t we drink it [recycled wastewater] directly, rather than recharge to the aquifer?’ also came up during the trial [13,17,33]. The Water Corporation also leveraged this strategy in the GWRS phase two in determining a construction strategy with the lowest impact to environmental resources and heritage sites for the 13km pipeline connecting the site to offsite recharge bores [20].

Conclusively, factors leading to the success of the GWRS may be summarised as follows:

- Recognition and acceptance of climate change effects on water resources and the will to explore ‘unpopular’ alternatives for groundwater replenishment.
- Commitment to a long-term and detailed planning process.
- Clear identification and proactive engagement of stakeholders ranging from regulators to the general community which resulted in productive collaborations.
- Access to evidence-based research on the viability of groundwater replenishment using wastewater supplies.
- Access to government financing which has meant that the Water Corporation would not be obligated to external or private sector financiers.
- Stakeholder support garnered through transparent and sustained dialogue with community members who constitute the bulk of Water Corporation customers.

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