THE BEENYUP ADVANCED WATER RECYCLING PLANT – AUSTRALIA'S FIRST LARGE INDIRECT POTABLE REUSE PLANT

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BACKGROUND

In 2016, the Beenyup plant was commissioned, and it became the first large plant in Australia using highly purified recycled water for groundwater recharge. The recycling of wastewater, particularly for indirect potable reuse, had been a highly controversial topic in Australia. Although many countries such as Singapore have shown how it can be done safely, there had always been opposition from segments of the public in Australia. Before the Beenyup plant was started, current regulations had defined any water treated through an advanced water treatment plant as wastewater, even though it was highly purified [1]. Various government agencies needed to work together to define the regulatory framework that would be required for the Groundwater Replenishment Trial (GWRT) which was the name given to the trial period for the testing that was done prior to the building of the Beenyup plant.

This paper will look at the GWRT, primarily focusing on the Advanced Water Treatment Plant reverse osmosis system and the problems encountered during the demonstration period. We will discuss the problems that were identified and how they were resolved. We will also discuss the full-scale plant (Beenyup Stage 1, and the expansion, Beenyup Stage 2, which was commissioned in 2019) and we will discuss some of the unique features employed by both plants.

INTRODUCTION

The southwestern portion of Western Australia has experienced a continual decline in rainfall over the past several decades. Combined with a continual increase in population, this has led to water supply issues in the capital city of Perth. Perth is the fourth largest city in Australia, with over 2 million residents in the greater Perth area. Although Perth had built a large seawater desalination plant in 2006 (and a much larger one in 2013), they needed to look at other methods of supplying the water needs of the residents, businesses, and agriculture. Seawater desalination can be very expensive as it uses a lot of energy, but it is much more accepted by the Australian public. All of the major Australian capital cities have built at least one large seawater desalination plant.

In Western Australia, a government owned business called the Water Corporation is responsible for managing water supply, wastewater, and drainage infrastructure assets. In 2003, the Water Corporation had discussions with staff from the Orange County Water District in California regarding groundwater recharge using recycled wastewater. Orange County had extensive experience with using highly purified recycled water for groundwater recharge, although one of the main purposes for the OCWD plants was to provide water for injection points near the ocean to prevent further seawater intrusion.

After several years of scientific studies and discussions on the required regulatory framework, it was agreed that a demonstration trial would be undertaken to assess the viability of using highly purified recycled water to recharge the underground water storage for the Perth region. The main underground storage of water in Perth is called the Gnangara mound, and it has been continually declining over the last several decades. This was causing problems such as trees dying due to their roots not being able to access water [2], and many people with bores needed to keep lowering their pump intakes to get to the aquifer. The Groundwater Replenishment Trial (GWRT) was undertaken from 2009 until 2012 to determine the technical feasibility of an Advanced Water Recycling Plant (AWRP), along with the policy and regulations that would be required to ensure the safety and community acceptance of such a plant.

I. GROUNDWATER REPLENISHMENT TRIAL (GWRT)

The Groundwater Replenishment Trial was started in 2009, with the construction of the Advanced Water Recycling Plant commissioned in November of 2010. The purified water from the AWRP was injected into the Leederville aquifer until December 2012.

The feed water to the plant is municipal wastewater that has preliminary, primary, and secondary treatment. Preliminary treatment uses bar screens to remove large objects and debris from the wastewater. This is followed by grit chambers which remove any grit and sand-like material before the wastewater is routed to the primary treatment. Primary treatment uses large tanks called settling basins or clarifiers, which allow the dirt, gravel, and other heavier organic solids to settle or sink to the bottom. Grease, oil, and other floatables are also removed here. Rotating arms help remove settled solids from the bottom and separated floatables from the top.

The secondary treatment that follows helps remove dissolved organic matter that was not removed during primary treatment. The treatment technologies used can include activated sludge process, trickling filters, clarifiers, and processes which use biological activity to break down organic matter. After the wastewater has gone through preliminary, primary, and secondary treatment, it is called secondary effluent which is usually discharged through an outfall pipeline to the ocean.

The AWRP takes this water that would normally be discharged to the ocean and treats the water to a highly purified state using several technologies. The first step is using ultrafiltration which removes particulate contaminants from the water. Suspended solids, protozoa, bacteria, and some viruses are effectively removed in the ultrafiltration step. The next step involves reverse osmosis which can remove most dissolved salts, organic chemicals, viruses, and pharmaceuticals. The final step involves ultraviolet treatment, which is the final disinfection step. It will destroy any remaining low molecular weight organic compounds including those that must be removed to parts per trillion levels. This process insures that unwanted biological materials and organic chemical compounds are effectively destroyed or removed.

The reverse osmosis system design for the GWRT consisted of two parallel trains with a 2 stage array. There were 15 vessels in the first stage and 8 vessels in the second stage, with 7 elements in each pressure vessel. Initially Koch RO elements were installed but they were changed to Hydranautics ESPA2-LD after 18 months. The pretreatment consisted of Memcor Ultrafiltration membranes. The design recovery was 75%, and ultraviolet light was used in the posttreatment. Sodium hypochlorite was added to the secondary effluent which formed chloramines due to the high levels of ammonia in the wastewater. A level of 2 – 3 ppm of chloramines is typically maintained in recycled wastewater plants to control biofouling.

1.1 Problems Encountered During the Trial

One of the main problems encountered during the trial was severe biological fouling was observed in the lead membranes. Aggressive cleanings up to pH 13 at 40°C were being done every two weeks and were unable to remove the biofouling and restore the dP's (which measure the plugging of the feed channels of the RO elements). These aggressive (and unsuccessful) cleanings will shorten the life of any RO membrane. After 18 months, the membranes were replaced, but with a new focus on using different methods of cleaning.

The first method tried was to "flip" the heavily fouled lead membranes around 180° and put the brine seal on the opposite end of the element. This lead element would then be placed in a tail position, such that the heavy deposit of biological foulant that had been at the feed end of the lead element was now at the tail end of the back element. These elements were drained and weighed before they were shifted, and after a few days of operation like this they were removed, drained, and weighed again. All the elements that were shifted lost significant amount of weight which was due to the water flow now "pushing" the foulant out.

Although this clearly showed benefits, you would not want to operate a plant like this due to the amount of physical labour required to flip the elements. The Water Corporation then did trials on a test skid using different cleaning methods, including "reverse cleaning" which involves cleaning the membranes in the reverse direction than normal cleaning (from brine end to feed end, instead of feed end to brine end). Reverse cleaning was clearly the most effective way to remove the biofoulant since it appeared to build up at the feed end of the lead membrane. In fact, their study showed that using just water in a reverse direction was more effective than using chemicals in a forward direction, particularly at higher flow velocities (Fig. 1). Following the testing performed by the Water Corporation, the RO skids were modified to allow reverse cleaning, which proved to be successful. When the full-scale plants were built, it was specified that the cleaning systems must be designed for both forward direction and reverse direction cleanings.

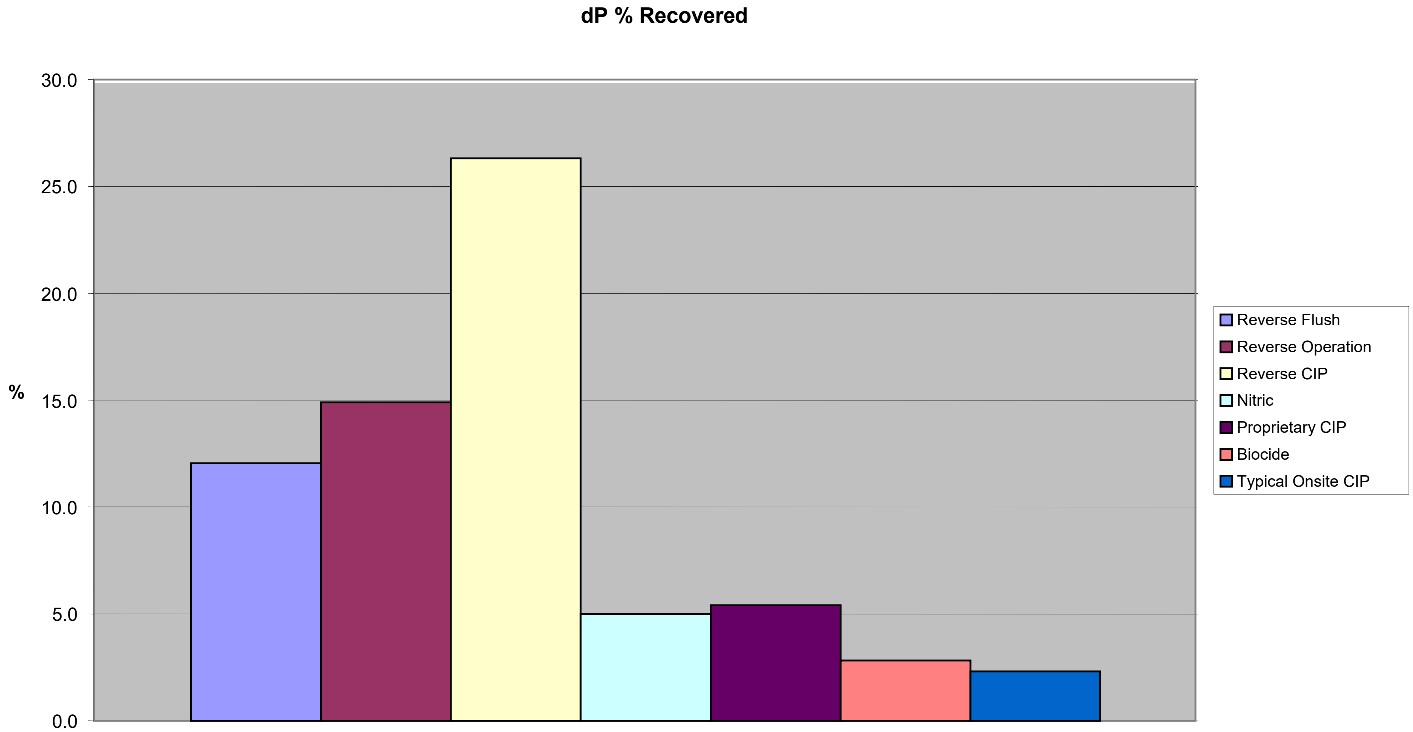


Fig. 1 – CIP Cleaning Study Results

Being able to clean the RO membranes was obviously very important, but the Water Corporation decided to look at the cause of the biofouling and how it could possibly be prevented. They commissioned a study by the Australian firm Aquatis which determined that one of the primary causes of biofouling was that instead of forming monochloramines (which are very effective at controlling biofouling), they were forming organochloramines [3], which have very little disinfection efficacy. Studies have found that organic nitrogen in the presence of monochloramine causes a definite shift of the monochloramine fraction to dichloramine (organic chloramine) fraction over time. This can be attributed to the hydrolysis of NH2Cl to HOCl with the HOCl reacting to form more organic chloramine. This reaction continues over time and results in a reduction in biocidal effectiveness. One way to counteract the effect is to increase the ammonia concentration which inhibits chloramine hydrolysis and organic chloramine formation. In addition, it reduces chlorine demand. This problem was only made worse by having a RO feed tank which increased the residence time and allowed the small amount of monochloramines that were formed to degrade into organochloramines. Current common analytical methods to measure chloramines cannot differentiate between monochloramines and organochloramines, so this threw another obstacle into managing the problem.

Testing was done at site to determine the optimal ratio of chlorine to ammonia. Two methods were found to be the most effective at ensuring a monochloramine concentration of 2 to 3 ppm for injection before the RO system. The first was a 4:1 chlorine:ammonia ratio with 3 mg/l ammonia concentration. The second method is a 6:1 chlorine:ammonia ratio with 2 mg/l ammonia concentration (this is used when

NH3 concentration in the feed water is a problem). Post ultrafiltration and pre-RO system injection seemed to be the best option since it maximizes monochloramine ratio over total chloramine. In addition, the ultrafiltration membranes are tolerant to chlorine and can be kept clean by regular chlorine backwashing, but the reverse osmosis membranes have very little tolerance to chlorine. Pre-forming chloramines is usually done in a separate mixing tank where either ammonium chloride or ammonium sulfate is mixed with sodium hypochlorite. This allows you to control the monochloramine formation since it eliminates all other competing reactions between ammonia, chlorine, and other components in the water. Following these changes to the AWRP, the time between cleanings decreased to once every 3 months (it had been once every 2 weeks at the GWRT prior to pre-forming the chloramines).

II. BEENYUP STAGE 1

Following the successful GWRT, the Water Corporation selected two teams to develop the preliminary design and costs for three separate capacities. In November 2013, a joint venture of CH2M Hill and Thiess (known as CHTJV) was selected to design, construct, and commission the 14 gigaliter per year Beenyup AWRP. The plant was successfully commissioned in 2016, and has 9 ultrafiltration skids utilizing Dupont UF modules (Photo 1) which operate at 92% recovery and a maximum flux of 49 LMH [4]. During commissioning, 5 UF modules were challenge tested with MS2 virus to ensure at least 3 log removal. They easily met this challenge as all 5 modules showed better than 5 log removal of the MS2 virus.

The reverse osmosis system has four trains, each with an array of 70 vessels in the 1st stage and 35 vessels in the 2nd stage (Photo 2). There are seven Hydranautics ESPA2-LD elements in each vessel, and the design recovery is 75%. The design flux rate is 19.2 LMH and there is a FEDCO energy recovery device that boosts the 2nd stage pressure. All RO elements required wet testing in the factory, and all elements needed to pass vacuum testing (ASTM D3923-08). The RO system needed to achieve 3 log reduction of virus/bacteria/protozoa. This was done on one train (Fig. 2) through Rhodamine-WT challenge testing (ASTM D6908-06). The RO membranes easily met the 3 log reduction criteria. The Western Australia Dept. of Health requires that both UF and RO challenge testing be repeated every year.

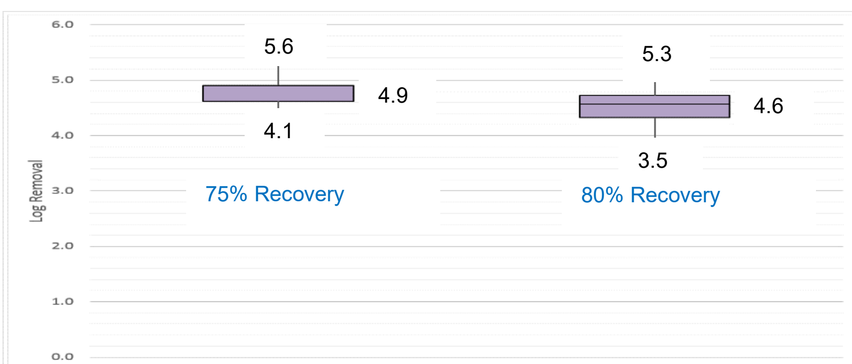


Fig. 2 – Rhodamine WT Challenge Test Results (courtesy of Jim Lozier – Jacobs Solutions)

The pressure vessels are manufactured by Protec Arisawa and they have auto-shim devices installed which allows for shimming the elements from outside the pressure vessels. The ultraviolet light disinfection system consists of two trains and was supplied by Calgon Sentinel. The key performance requirement for the UV light disinfection was 4-log virus inactivation.

The plant has been in operation for almost 6 years now and it has met all permeate quality specification requirements. There still is a bit of an issue with front end biofouling, but it is much better than what was experienced during the GWRT testing. Normalized data (Fig. 3) shows the differential pressure rise in the 1st stage. Normalized permeate flow graphs show that permeability is restored to baseline after cleaning. Normalized salt passage has slowly increased from just under 2% to just over 3%, but this is over a period of 6 years and is expected due to the exposure of the RO membranes to 2 - 3 ppm of chloramines. Thin-film composite RO membranes can tolerate about 200,000 ppm hours of chloramine exposure before salt passage doubles (this is in the absence of transition metals such as iron or manganese, which can reduce it to 20,000 ppm hours). Cleanings are done about every 3 months and consist of Hydrex 4705 at pH 11 and citric acid at pH 3 to 4.

A complete set of replacement ESPA2-LD RO elements have been purchased and are scheduled to replace the existing ESPA2-LD elements early in 2023. The main reason for replacement of the membranes is the gradual increase in salt passage over the six years of operation.

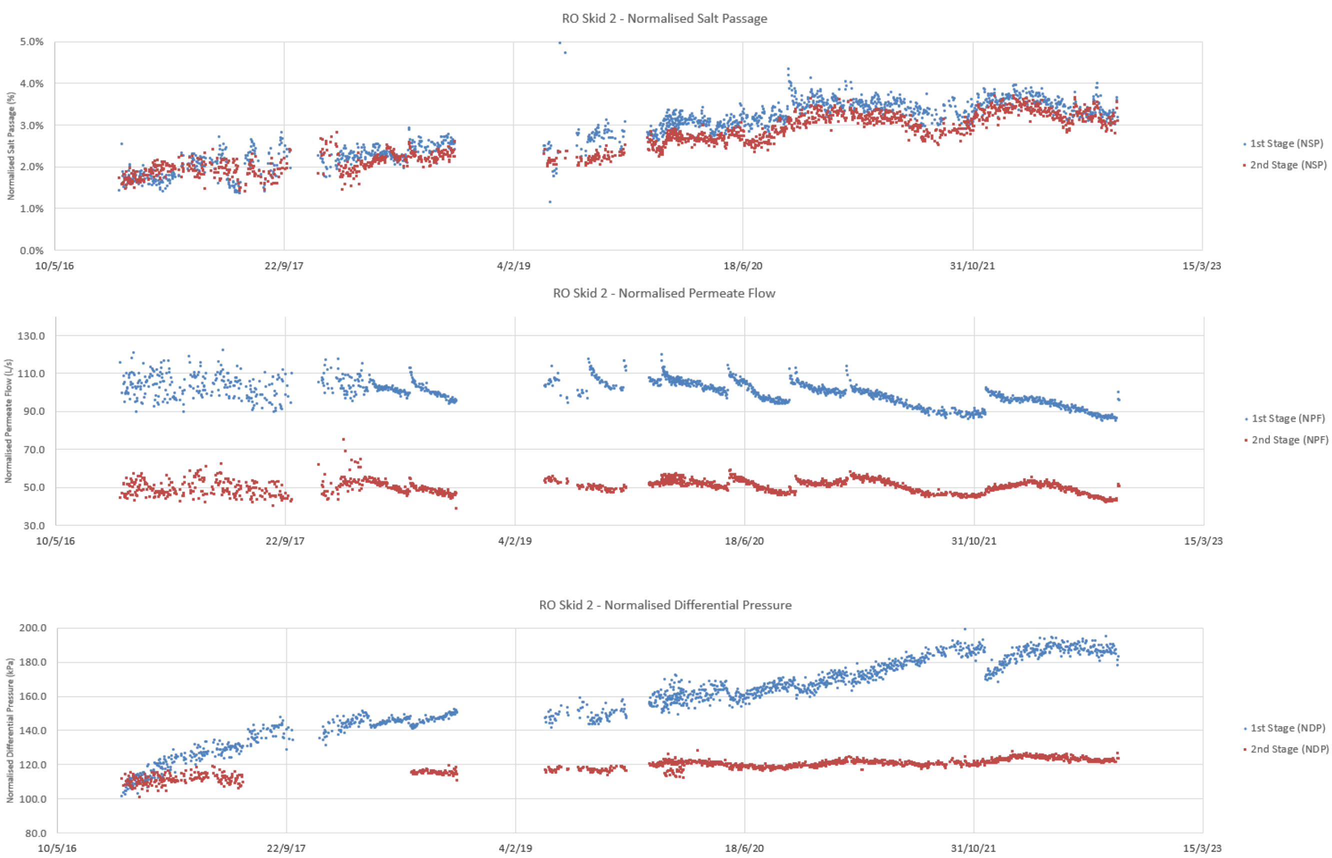


Fig. 3 – Beenyup Stage 1 Normalized Data

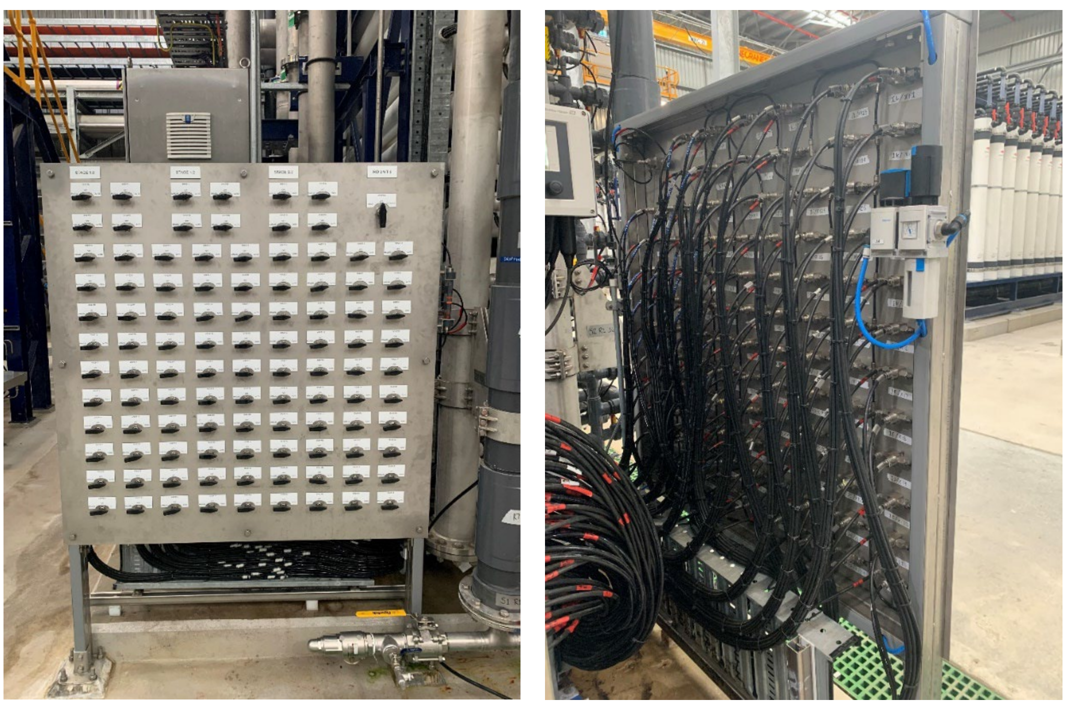
Photo 1 – UF Pretreatment

Photo 2 - Beenyup Reverse Osmosis Trains

III. BEENYUP STAGE 2

The second AWRP was built next door to the Beenyup Stage 1 plant by a partnership of Clough and Suez. Beenyup Stage 2 is very similar to the Stage 1 plant but with a very unique feature added. At AWRP facilities, permeate conductivities are the primary method used to determine how well the membranes are performing. Conductivity is a measurement of electrical transmission in water, and the more salts in the water, the higher the conductivity. If conductivity values are low, this means the water has very little salts, and a very low chance of having much larger bacteria and viruses passing into the clean water. The theory is that if the much, much smaller salts are not passing through the membranes, or bypassing any o-rings or seals, then the much larger bacteria and viruses cannot be getting into the clean water either.

While conductivity is continually monitored in most plants, it is usually a combination of vessels that is measured. For example, the 1st stage (75 vessels total) permeate conductivity would be continuously measured and recorded by the SCADA system. But when this many vessels are contributing water to the total sample, one leaking vessel would hardly be noticed. To address this concern, a water sampling panel was installed at the Beenyup expansion (Photos 4 and 5) that consists of many microvalves that constantly switch permeate from different pressure vessels to a conductivity meter that allows incredibly frequent monitoring of individual pressure vessel performance. Each pressure vessel has the permeate conductivity measured every 5 minutes. This data is sent to the SCADA system and recorded, and alarms are set to alert the staff if any conductivity numbers are out of range. If any pressure vessel indicates a higher permeate conductivity value, the pressure vessel can be probed by placing tubing down the center of the vessel to measure the permeate conductivity at various points along the length of the vessel. This helps determine where the problem is located, i.e. a particular RO membrane or interconnector, so that they can be repaired or replaced. This truly sets a new standard for ensuring the safety and reliability of the recycled water.



Photos 4 & 5 – Continuous Conductivity Monitoring Panel – Front and Back

V. CONCLUSIONS OR RESULTS

The Beenyup Advanced Wastewater Recycling Plant has been successfully supplementing Perth's water needs for almost 6 years now. Several issues were identified during operation of the demonstration plant during the trial period. The main issue was severe biological fouling, which was able to be addressed through changes in how chloramines were formed and dosed into the feed water. Several unique features were added to the full-scale plants, such as reverse cleaning and continual individual pressure vessel conductivity monitoring. The Water Corporation has laid the groundwork for how indirect potable reuse can be safely applied and it is anticipated that many more plants such as Beenyup will be built in the coming years.

VI. REFERENCES

1. Bettini, Y., Head, B. (2016) WA Groundwater Replenishment Trial. A case study of creating the enabling environment for regulatory change
2. Groom, Phillip K., Froend, Ray H., Mattiske, Elizabeth M (2000). Impact of Groundwater Abstraction on Bankia Woodland, Swan Coastal Plain, Western Australia
3. Schrotter, JC (2013) Optimisation of the 5 MLD Advanced Water Recycling Plant (commissioned investigation by the Water Corporation)
4. Lozier, J. (2016) Beenyup Advanced Water Recycling Plant. The Perth, Australia Groundwater Replenishment Scheme
5. Hamilton, S., Loi, C., Holme, R., Trolio, R. Operational Learnings from Membrane Biofouling of a Groundwater Replenishment Scheme