Development and Testing of a Laboratory-Scale Automated Blending System for the Supply of Water to Remote Communities

ENG470 – Engineering Honours Thesis

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I, Rhys John Gustafsson, declare that the work presented herein has been completed in accordance with Murdoch University policy. The work is original except the blending concept which was initially proposed by Mario Schmack and Martin Brezger of Moerk Water Solutions, and where indicated by reference. No part of this work has been submitted elsewhere or in any other course.
Abstract
There is a need for water treatment and supply systems in Australian remote communities to mitigate water scarcity and quality issues that they often experience. A concept involving the blending of continuously produced reverse osmosis (RO) permeate with variable flow rate raw water bypass to meet fluctuations in demand has been proposed to address these water supply issues. This project developed a laboratory-scale version of the blending process with the objective to test a blending strategy and apply knowledge gained in hardware and software development. Two streams of different salinity water were used to simulate the RO permeate and raw water bypass. The raw water bypass flow rate was controlled by a solenoid. The water demand was sensed by an equalisation tank employing a continuous level sensor. LabVIEW was the software used to control the system via the blending algorithm that was developed. The blending strategy which was applied demonstrated that it is capable of maintaining steady states, with the exception of extreme cases of simulated demand. It is capable of maintaining simulated continuous operation of the reverse osmosis unit, whilst also maintaining the level of water in the tank above 50%, thereby demonstrating that the proposed field-scale system can achieve its aims. Application in the laboratory-scale system of hardware components, such as the level sensor, and software components, such as the blending strategy, should be translated to field-scale for trials. This project identified blending strategies which may be tested in future work that could allow for improved product water quality, and fit-for-purpose water supply, thereby increasing the appropriateness of this technology.
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Glossary

ADWG – Australian Drinking Water Guidelines

PID – Process and Instrumentation Diagram

RAESP – Remote Area Essential Services Program

RO – Reverse Osmosis

RWB - Raw Water Bypass

SP – Simulated Permeate

TDS – Total Dissolved Solids

UF - Ultrafiltration
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1.0 Introduction

Many remote Australian communities are located in arid or desert regions where there can be a limited amount of water available at a below standard water quality (ATSIC 2002). For the majority of these communities poor quality groundwater is the only source of water and it often has high concentrations of Total Dissolved Solids (TDS) and other contaminants (Wright 2002). As a result, residents can find the water unpalatable and rely on alternative water provision for drinking, which comes at a significant cost. Additionally, water hardness is another common issue; it causes scaling of water infrastructures and results in damage to water fittings, fixtures and wet areas in the homes, impacting on personal hygiene and facilities functionality. This causes significant costs for the service providers and communities for repairs and maintenance. Issues of wastage through leaks and poor conservation practices are common.

Many remote communities have a service provider which is responsible for maintaining water, wastewater and power infrastructure (OAG 2015). The typical approach is to apply a design guideline which specifies that water supply infrastructure must have the capacity to produce a certain volume of water per, person per day. This approach aims to ensure there is enough water for the community, in consideration of the quantity of water wasted through leaks and poor conservation practices, which is a common occurrence in remote communities (Yuen 2004; Ross et al 2014). However this results in the need to build systems large enough to produce this quantity of water, which leads to increased system complexity and cost. Increased complexity reduces the robustness of these systems (Thomas 1997) and a high cost means that improved water supply for these communities is beyond their financial capacity, leaving them with minimal alternatives but to remain with their sub-standard system.

The two remote Aboriginal communities of Wakathuni and Innawonga located in the Pilbara region of Western Australia are examples of locations having long standing issues as described above. In early 2015 IBN (Aboriginal Trust of the Yinhawangka, Banyjima and Nyiyaparli people), which is the service provider for both of these communities, sought the advice of Mario Schmack Water Consultancy to investigate these issues and propose a way forward to overcome them. Several water delivery options were investigated and evaluated for their social, technical, financial and legislative performance.
1.1 Summary of all treatment options
The water delivery options that were considered in the report prepared by Mario Schmack Consultancy (2015) for Wakathuni and Innawonga are summarised here:

Option I – RO for whole of supply

An RO unit supplies all of the water for the community.

Option II - 20/80 Dual water supply

A set fraction of the water supply, e.g. 20% is treated to the highest quality by RO and is used for drinking, food preparation and cooking, the remaining 80% is treated by filtration and softener only.

Option III – Automated blending design

This system operates in an automated blending modus, with a set volume of 100L/p/day treated by RO and a further 700L/p/day (treated by UF and softener) being available through bypass. As demand increases the flow rate of bypass water increases accordingly.

Option IV – Water bottling station

A small RO unit is installed to treat a small portion of water (e.g. 15-20L/p/day), to highest quality, solely intended for the filling of water bottles for drinking and cooking purposes.

Option V – Household-scale RO water treatment

A centralised UF and water softener unit installed in the existing reticulated line to supply all connected houses. Each household would be equipped with a decentralised water treatment unit, installed outside the house, supplying water for drinking and cooking purposes only.

Option VI – Roof mounted solar still for fit-for-purpose water provision

A number of solar stills on each roof would be used to feed a product storage tank in the kitchen and provide highly purified water for drinking and cooking, with expected production of each unit being 15L/day.

1.1.1 Selection of most suitable treatment option

The whole of supply approach (Option I), would require significant infrastructure upgrade, resulting in large additional investment, estimated to be $200,000 to $300,000 (Mario Schmack Water Consultancy 2015). The 20/80 system (Option II) allows much smaller volumes of brine to be produced, however it requires extensive pipework in order to deliver a dual water supply to each
household. This would result in a significant cost and an unacceptably high risk of damaging the existing DoH-owned infrastructure. The automated blending design (Option III) requires little infrastructure upgrades, leaving the existing infrastructure unaffected.

For the low volume options, the RO water bottling station (Option IV) is relatively inexpensive, with a short payback period. It is envisaged that the main disadvantage is the physical labour required to deliver the water from the bottling station to the consumer (Mario Schmack Water Consultancy 2015). The household-scale RO treatment (Option V) eliminates the physical labour component, however operating large micro-RO units is very inefficient and costly, regarding energy consumption (Mario Schmack Water Consultancy 2015). Finally, the low-tech roof mounted solar stills (Option VI) are limited by their short lifespan and high level of maintenance required that arises from their placement on individual house roofs.

It was concluded that the automated water treatment and blending system (Option III), would be the most suitable option, with Moerk Water Solutions expressing an interest in driving the development of this technology. The major factors that contributed to this option being the preferred water supply method are as follows:

- Able to meet design guidelines for the volume of water to be delivered, with a smaller size RO, which reduces cost, thereby increasing the accessibility of improved quality water to communities and overcoming one of the major cost issues associated with the guideline approach;
- Increases the lifetime of RO membranes and reduces system complexity by continuously running the RO unit;
- Overcomes issues of being able to supply variable quantities of water which is brought up from communities often having transient populations;
- Reduces the volume of brine that is produced;
- Adds salt to permeate which is necessary for the palatability and corrosion control of treated water from RO units.

1.2 Aims
This project was the next phase in the development of this concept, which proposes to mitigate water scarcity and poor water quality in a financially viable manner. The aim of this project was therefore to develop a laboratory-scale simulation of an automated blending system and to demonstrate the appropriate hardware and software strategy for its implementation.
1.3 Objectives

1. Determine the appropriate system configuration and components to develop a laboratory-scale version that is as translatable as possible to the full-scale system.

2. Source components and adjust the system as necessary according to their availability, then test these components so they are able to be operated in a controlled manner.

3. Develop a software program capable of interfacing with the necessary system components and controlling the process. With all individual software and hardware components prepared, run system as a whole and test for accuracy of outputs, then adjust as necessary.

4. With system operating accurately, conduct experiments to test the dynamics of the system and the performance of the blending strategy.

2.0 Background

2.1 Remote communities in Australia and their water supply services

2.1.1 Introduction

Approximately 2% of the Australian population lives in remote locations as reported by ABS (2008). The classification of ‘remote’ is based on a calculation of the distance by road to major services centers (Commonwealth Department of Health and Aged Care 2009). Remote communities have been classified as falling into four categories (Harrison 2001): mining, pastoral/agricultural, tourist and Aboriginal.

Most of remote areas are categorized as semi-arid and arid, with the availability of water typically being restricted to brackish reserves (AWRC 1987). A quarter of the remote population is Aboriginal and Torres Strait Islander people (ABS 2011), with 60-70% of these communities relying on groundwater reserves for their water supply (Harrison 2001, ABS 2007).

The sophistication of the community’s water supply is generally related to the size of the community (Department of Families, Housing, Community Services and Indigenous Affairs 2010). For communities located close to main towns they are often connected to the town water supply. In the case of Western Australia there are 41 communities connected to Water Corporation infrastructure (DoW 2009). Major communities (population greater than 100) usually have locally sourced water, with their supplies treated and managed by a service provider with water quality testing taking place monthly or quarterly. In Western Australia there are 91 of these communities managed under the service provider RAESP (Remote Areas Essential Services Program) (DoW 2009). Minor communities
are generally self-supplied and rely on small or private water supplies which are rarely treated or tested for water quality. In Western Australia there are 155 communities classified as self-supplied (DoW 2009).

2.1.2 Overview in performance of remote communities meeting water quality guidelines

Groundwater quality varies in its concentration of dissolved salts. Some Australian communities have water supplies with a TDS of up to 1500mg/L, which is considered the maximum tolerable limit for salinity (NSW Public Works 2011). Due to the reduction in palatability of water at high levels of salinity it may reduce the amount of water people consume, which has been known to lead to health issues such as kidney and gastric disorders and hypertension (Willis et al 2004). It is recommended that for good palatability TDS in drinking water should not exceed 600mg/L, and concentrations greater than 1200 mg/L are unpalatable (NHMRC 2011).

Salinity is not the only water quality parameter that is of concern. Reporting from the OAG (2015) showed that Western Australian remote community water supplies are often not meeting Australian guidelines. It was found that 80% of communities failed drinking water tests for Naegleria or E.coli (OAG 2015) which are capable of causing life threatening illnesses. It was also found that one in five communities exceeded safe levels for nitrate or uranium (OAG2015).

The concentration and the type of contaminants in water sources are significant in selecting the appropriate technology and creating an optimal design. Ultimately the goal with water treatment technology for drinking water use is to at least meet the Australian guidelines.

2.1.3 Water demand in remote communities

Typically a design guideline for the amount of water required per person, per day is used to inform the output characteristics for a water supply system in remote communities. This is set by the service provider, which for most of WA is RAESP, they have applied a guideline of 800L/person.day. This is comparatively high relative to city dwelling counterparts, such as Perth which has an average residential consumption of 290L/person.day (Water Corporation 2009). There have been a number of reasons attributed to the high figure applied for the design guideline in remote communities, which include, but are not limited to:

- Inability to address technical issues that result in water losses such as leaks;
- ‘Lack of ownership’ mentality, resulting in residents taking little responsibility for water conservation.
Therefore before any kind of water system is designed, an assessment of where excess demand is occurring should take place. This will reduce unnecessary wear on the system brought about from over production and reduce stress on the groundwater resource. It has been suggested that 20–50 L/p/d of high-quality water is required for drinking and cooking and 100-150L/p/d of lower quality water is appropriate for bathing or washing, cleaning and swimming (Yuen 2004; Department of Families, Housing, Community Services and Indigenous Affairs 2010). Higher amounts of water needed for lower water quality requirements such as firefighting, landscaping, laundry and livestock. This would suggest that the 800L/p/day figure is much higher than what is actually required. Yuen (2004) is critical of the design guideline approach and recognizes that the factors influencing water consumption in individual communities are highly complex and variable, making it difficult to provide a precise estimate for design supply.

By applying a design guideline of 800L/p/d it reduces the risk that communities will be without the their required volume of water - however in doing so it inadvertently results in less communities being able to have improved access to water. This is because the cost to commission a system capable of producing this quantity of water is so high that it is no longer viable to put in place and the community is left with no choice but to continue using their sub-quality water supply. If this reductionist approach is to continue there will need to be systems designed to overcome this cost burden. This is therefore one of the main driving factors for the blending strategy proposed in this project.

An understanding of the pattern of use and the peak demand for water in remote communities is especially important for the proposed automated blending process as it impacts on the volume of water in the tank and therefore the blending ratio and quality of water. So in order to be able to simulate expected demand conditions it was necessary to research water use patterns in remote communities. Typically for urban residential water use profiles there are two peaks in use of water throughout a 24 hour period (Loh and Coghlan 2003; Athuraliya, Roberts and Brown 2012). Early morning before people leave for their occupation caused by showers and washing appliances and late evening when people are cooking and showering (Athuraliya, Roberts and Brown 2012).

The demand profile can differ between urban and remote communities. For example in remote communities there is no drop to zero or close in water demand during the night period due to leaks. Leakage is also a significant factor to consider in overall water demand and water use profiles. Ross et al (2014) found that 20% of consumer demand can be lost to continuous leaks, with a further 14% lost to intermittent leaks, this is consistent with other reporting on the matter (Yuen 2004).
Also if some of the community members are not leaving for their occupation during the day such as work or school then water use will continue and the trough during the middle of the day may not be as significant. So in general it is assumed that overall water use is higher with the peaks not as pronounced due to higher troughs. Applying these figures, a water use profile was assumed for the community as shown in Figure 1. This uses an average daily per person water demand of 200L, with a 12% leakage rate (24L/p/day). This equates to a daily average for the community of approximately 1200L/hour as shown in Figure 1. The water use characteristics are known to vary significantly, so it is possible that this may not be accurate for the case study sites. However with the information available an estimate of a possible water use profile has been developed.

![Assumed community water use profile](image)

Figure 1: The assumed 24 hour water use profile for the case study community, Wakathuni. The red line represents the average hourly water consumption for the whole community.

### 2.1.4 Desalination technologies in remote communities

As previously stated the quality of water in remote communities is often below guideline levels creating health risks and sometimes damage to infrastructure. It is therefore necessary for some form of treatment to bring the water quality to an acceptable level. Total Dissolved Salts (TDS) is the main water quality parameter requiring treatment for the case study sites and therefore some form of desalination technology is required.

The major desalination processes available may be categorized as thermal or membrane (Shitat and Riffat 2013). The decision to use RO as opposed thermal desalination process is typically dependent on the availability of thermal energy, with thermal desalination process being more energy intensive (Shitat and Riffat 2013). However the selection of the most appropriate treatment method is not within the scope of this project. The selected desalination technology for the case studies in this project was RO, the justification for this decision can be viewed in Mario Schmack Consultancy (2015).
It is recognized that for communities utilizing brackish water, most installations use traditional RO membrane technology (NSW Public Works 2011). RO has received criticism for its applicability in remote communities due to the maintenance and associated costs required to replace membranes, brine disposal requirements and high energy consumption (Yuen 2004, Werner 2009 and CAT 2010). These issues must be considered for field-scale implementation.

As with all kinds of technology there are specific requirements for it to meet if it is to be appropriate for a remote community, some important issues that should be considered include:

- Selecting a technology that is robust, and simple, and capable of sustaining life in a remote community with a harsh environment;
- Identifying the felt, normative and expressed needs of the community;
- Determining how much the community values the resource and how much they want the technology;
- Providing an appropriate level of education and engagement of community members to appreciate the technology and be capable of maintaining it;
- Determining the water treatment level suitable and desired for community needs.

2.1.5 Reverse osmosis
Reverse osmosis applies the principle of osmosis, whereby an ion is transported from an area of higher concentration across a semi-permeable membrane to an area of lower concentration. The pressure created by the solvent when a solute excluding membrane is placed between two solutions to equalize the overall concentration is known as osmotic pressure. The direction of solvent flow is determined by its chemical potential which is a function of pressure, temperature and concentration of dissolved solids. RO is therefore the process whereby pressure greater than the osmotic pressure is applied on one side of the membrane, reversing the osmotic flow and forcing the solvent to travel from the solution of higher concentration into the less concentrated solution. The process generates two products – a freshwater stream low in salinity (permeate) and a highly concentrated ‘brine’ solution, containing salts and other constituents rejected by the membrane.

2.1.6 Blending of water for water quality purposes in remote communities
The automated blending system which is the focus of this report aims to address some of the major issues that have been identified with RO in remote communities. By running an RO unit 24 hours per day that produces 1/8th of the design guideline total water requirement, the cost for the system is reduced due to a decrease in size of the RO unit and associated equipment. There is also less brine required to be disposed of, and a decrease in the amount of membranes required to be replaced.
The process of blending water to reach a desired concentration for drinking water is not a novel practice for remote community water supplies. Werner (2009) notes “there are a range of water management practices which can, and are already being used in some remote communities to overcome recognized shortfalls in water quality, such as dual supplies (e.g. utilizing rainwater as a potable source and bore water for non-potable use) and ‘shandying’ of poor quality bores with better quality ones to reduce quality problems”. The process of blending RO permeate with feed water is also widely practiced for many different applications, including for drinking water, with the primary purpose being to achieve a certain salinity of permeate (Lewabranie 2012). One particular example of this is the water supply for the town of Dalby, which is met completely by an RO system. Feed water is blended at a 5:1 ratio to produce final product water with salinity of 400mg/L (NSW Public Works 2011). However blending of water controlled by the demand of users has not been documented. This project is therefore focused on developing a laboratory scale demonstration of this automated blending process to aid in developing the automated blending process.

3.0 Proposed system configuration for laboratory testing

The preliminary full scale system configuration is shown in Figure 2, the purpose of the system is to produce water at an acceptable level of quality without unnecessarily producing large volumes of high quality water, which is both wasteful and costly. Groundwater is pumped form the bore and is softened by an anti-scaling and sodium-bisulphite unit to reduce fouling on the membrane and is stored in a header tank. The header tank acts as a buffer of water supply to the equalisation tank if there are power outages or other issues; there is typically 2-5 hours worth of storage in these tanks. Water from this tank is pumped via a high pressure pump that feeds the RO unit and the rest is bypassed to the equalisation tank. The water entering the header tank is tested for its salinity. The volume of water entering the equalisation tank is determined by the control system which actuates an electronic proportional control valve or solenoid. The permeate and bypass streams mix with chlorine at the same location to ensure proper mixing before entering the equalisation tank. The use or disposal of the brine discharged from the RO unit has not yet been determined. A conductivity sensor reads the salinity of water that is being sent to the users to ensure water quality is as expected and within guidelines.

A major objective of the automated blending system is to have the Raw Water Bypass (RWB) flow rate respond so that it is possible for the RO to run 24 hours per day, which is important for a number of reasons. Firstly, by having the RO produce the required daily amount of permeate over 24 hours as opposed to a shorter time frame it reduces the size of the RO and associated equipment. Secondly, if the RO is required to shut off it adds complexity to the system, creating a greater chance
of failure. If an RO is shut off, and damage to the membrane is to be avoided it is required to have a tank that stores permeate and encases it until it is needed to produce permeate again. The system components required to do this incur extra cost and have been known to cause issues to due to the nature of their sporadic use in systems like this (Thomas 1997).

Figure 2: Preliminary field-scale system configuration.

Figure 3: Laboratory-scale system developed for project.
The purpose of this project was to optimise the blending process, and therefore there was no need to incorporate the other system components (from the bore pump to the RO unit), as would be present in the full scale system. The laboratory scale system used to demonstrate and test the blending component of the full scale system can be seen in Figure 3.

The primary focus of the laboratory-scale system was to observe the dynamics of water rising and falling in the tank due to water entering and leaving it. The equalisation tank was sized so that its height was the same as the dynamic range of the full-scale tank. This allows the blending algorithm developed to be applied to the full-scale system, as well as the level sensor that is used to sense over this range. The process for sizing the tank is described in Section 4. In determining the most useful laboratory-scale system the rule of thumb was applied - maximising the number of components that do not need modification before full-scale implementation.

The range of flow rates that must be controlled can also be applied to the full-scale system. The maximum volumetric flow rate of the system occurs when there is a 7:1 source: permeate ratio. The system components such as the valves and pumps must be able to output and control in these ranges. The flow rate of permeate is determined as follows (using Wakathuni as an example):

Equation 1

\[ \frac{800 \text{ L}}{\text{person.day}} \times \frac{1}{8} \times 135 \text{ people} \div \frac{24 \text{ hr}}{\text{day}} \div \frac{60 \text{ min}}{\text{hr}} = 9.4 \text{L/min} \]

Note, the 1/8 factor in Equation 1 arises from the 7:1 source:permeate ratio. In the case of the laboratory-scaled system, the RO unit that would have been used is documented to produce permeate between 50 and 100mL/min and therefore the system was sized based on this figure. Initially this was the case and the maximum bypass flow rate was 700mL/min, however this solenoid became faulty and required a replacement. The replacement solenoid that was used in conjunction with the pump supplying pressure was capable of producing a maximum flow rate of 390mL/min, this therefore required that the simulated permeate (SP) have a flow rate of 55.7mL/min.

4.0 Materials
A significant aspect of this project in terms of workload was sourcing the appropriate equipment to fulfil the requirements for the system. This process involved identifying system requirements and the specifications such as flow rate and output signal and making sure all components were compatible with each other. The next step was to investigate whether the required piece of equipment existed and whether it was available at an appropriate price. The details of the purpose
and functionality of each piece of equipment is explained in this section, a summary of the equipment used for the project is contained in Appendix A.

4.1 Solenoid

The purpose of the valve is to control the flow rate of the source water stream between 0mL/min and 390mL/min. Initially an electronic proportional control valve was thought to be the most suitable instrument to use as it allows a constant flow of water to be maintained (i.e. at any instant there will be flow of water) and it was thought to likely be the type of valve used in the full-scale system.

After contact with local suppliers, Murdoch University technicians, internet searches and looking through suppliers with an extensive range such as OMEGA, it was found that these are very difficult to source and very expensive due to the low flow rate that it is required to control. The flow rate range required to be controlled is of 25mL/min to 700mL/min. The reason why this flow range is required is because the blending ratios of (permeate:source water) 1:7 and 1:0.25 that are to be tested have their volumetric boundaries dictated by the permeate flow rate produced by the demonstration rig RO equipment, which is 100mL/min. Local supplier Fusion was unable to source an electronically actuated valve and instead offered a manually controlled bore throttled valve and pneumatically actuated diaphragm valve. The manually controlled valve was not suitable as it is not possible to be operated in an automated manner, and the pneumatic valve was not suitable because it is desired to control the valve by electronic signal as opposed to air, due to its applicability to the field scale system.

A solenoid was selected as the next best option as they are readily available and will be able to achieve the desired flow rate range of 0mL/min to 390mL/min. A solenoid is a device that converts electrical energy into a mechanical movement, resulting in flow through it either being 100% or 0%. The type of solenoid used in this system was a zero differential solenoid (see figure 7A), as opposed to a differential valve as the pressure supplied in this system is not sufficient to force the flow of water through the solenoid when open for a differential solenoid. The solenoid is controlled via a 5V voltage signal which opens and closes the circuit that supplies 12VDC power to allow the solenoid to open. A summary of the pros and cons of the selected method of controlling water can be seen in Table 1.

Table 1: Pros and cons of using a solenoid for the laboratory-scale system.

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheap compared to proportional electronic valve</td>
<td>Does not allow for smooth control of water flow</td>
</tr>
</tbody>
</table>
Solenoids much easier more widely available and therefore easier to replace
Simpler than electronic proportional valve and therefore likely to be more robust

4.2 Level sensor

The level sensor was required to sense the level of the water in the tank and send a continuous signal to the LabJack. The data received in this device was utilised to inform the flow rate of water that the solenoid controlled.

The criteria for the level sensor was to send continuous electrical signal output, de-couple sensor from fluid to reduce potential for corrosion, have a range of at least 110cm and be relatively simple to set-up and calibrate. There are many different technologies of level transmitters available that meet this criteria such as capacitance, ultrasonic, piezo-resonant, electro-optical and more. The selected level transmitter was ultrasonic for its local availability, and ease of installation and calibration. The chosen level transmitter was an ultrasonic Flowline DL10-0 and has a range of 125cm as can be seen in figure 7B.

Ultrasonic level transmitters generate ultrasound waves which consist of high-frequency sound waves (~20kHz) that are inaudible to human beings (Bruneau and Scelo 2006). The fluid level is detected by measuring the return time of the ultrasound wave from the surface of the liquid. A summary of the pros and cons of the selected method for measuring water level can be seen in Table 2.

Table 2: Pros and cons of the selected level sensor.

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-contact</td>
<td>Price</td>
</tr>
<tr>
<td>Easy to install and calibrate</td>
<td></td>
</tr>
<tr>
<td>More robust than electronic proportional valves</td>
<td></td>
</tr>
</tbody>
</table>

4.3 Signal conditioner

The signal conditioner is required to receive analog signal from the sensors used in the system and send analog signal to the solenoid. This instrument is therefore responsible for communicating between the PC (LabVIEW) and the instruments.
There are many different types of signal conditioner available to perform what is required in this system. The LabJack U12 series was selected (see Figure 7C) because it was much cheaper than other options and staff within the university were familiar with it and could therefore assist in installing drivers and using in LabVIEW if necessary. A summary of the pros and cons of the selected signal conditioner can be seen in Table 3.

Table 3: Pros and cons of LabJack signal conditioner.

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheap</td>
<td>Does not accept current signals</td>
</tr>
<tr>
<td>Assistance available if required at University</td>
<td>Not available to purchase locally</td>
</tr>
</tbody>
</table>

4.4 **Conductivity meter**

The conductivity meter measures the salt concentration of the mixed permeate and source streams. This measurement takes place before water enters the tank, so that the accuracy of the control system in calculating a predicted concentration of the blended water can be checked.

This instrument was already a part of the laboratory so there was no need for a selection process (see Figure 7D). However if it was necessary to select a conductivity meter, an instrument capable of sending real time data to a PC would have been selected. As this would have provided another process variable that could have been acted on for controlling the system. A thorough investigation into the possibility of using this instrument to send real time data was conducted. This involved reading manuals, searching the internet, contacting manufacturers and talking with academic staff at Murdoch University with expertise in this area. The conclusion was that there is no existing functionality to allow for this to happen, however it is possible to program a driver for the meter in LabVIEW so that real-time communication between LabVIEW and the meter can occur. It was noted by others with more expertise in this area that this will be a difficult and time consuming task to complete and therefore has been omitted from the project. The conductivity meter does however have software that enables data to be viewed on a PC in real-time and exported to excel manually by the user for later interpretation of results.

4.5 **Permeate and source water mixing vessel**

The concentration of the RWB and SP mixture is required to be measured so that the performance of the control system can be monitored. A mixing vessel as seen in Figure 5E,F was used to mount the conductivity sensor from which conductivity measurements were recorded. This method was
applied because the flow rate was so small that instantaneous measurements of the water entering the tank would not result in a sufficient depth of water to submerse the conductivity probe.

The mixing vessel allowed the permeate and source water to mix before entering the equalisation tank, thus averaging the salinity concentration measured over the short residence time of water in the mixing vessel as determined by the flow rate of the source stream. This allows for a more smoothed concentration of water entering the tank, which would otherwise have pulses of higher concentration caused by the solenoid opening and closing. If mixing in the vessel is not adequate, the salinity measurements taken will not actually represent the concentration of the water entering the tank at any time. This issue can be at least partially overcome by having the lower density permeate stream enter the container at the bottom and the higher density (and more saline) source water enter at the top. One stream will rise and the other sinks, therefore causing mixing. If a solenoid is used in the full-scale system it may be necessary to include this in the system as a means to confirm the concentration of water entering the tank.

4.6 Equalisation tank

The purpose of the equalisation tank in combination with the level transmitter is to sense the demand from the community with this information being used to control the flow rate of water that is to refilling this tank. In order for the results obtained in the laboratory-scale system to be best applied to the full-scale system it was necessary to size the tank so it would represent the full-scale system. The method for sizing the tank was therefore as follows:

- RAESP design guideline = 800L/p/day
- Community of Wakathuni has population of 135
- IBN has requested 2 days worth of storage

Therefore size of equalisation tank will be:

Equation 2

\[
800 \frac{L}{\text{person}.\text{day}} \times 135 \text{ persons} \times 2 \text{ days} = 216000L
\]

The top half of the tank was selected as the range in which the tank volume would be controlled. This ensures that under extreme high use conditions there will be at least one day’s worth of storage if flow into the tank ceases. The height of the tank is the dimension that is being measured to interpret the dynamics of the system. It was therefore necessary to use a tank that had the dimensions we were concerned with. A review of Australian tank suppliers showed that a height of
2.2m is typical for tanks of this volume. This figure has therefore been assumed for sizing of the laboratory-scale system. As can be seen in Figure 6, the sensing equipment is only utilised in the top half of the tank, this therefore requires a sensor with range of at least 1.1m. Level (A) as seen in Figure 6 corresponds to the height at which all equipment is switched off so that overflowing of the tank does not occur. Points (B) and (C) in Figure 6 represent the extreme RWB responses to level in the tank of zero and maximum by-pass rates, respectively.

![Diagram of the field-scale tank (not to scale).](image)

**4.7 LabVIEW**

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) was the program used to receive input data from the system, such as the level in the tank and to apply the blending strategy through controlling the solenoid. It was selected as the preferred programming platform to be utilised in this system as one of its main applications is controlling physical processes such as this.

LabVIEW is a system-design platform and development environment using a visual programming language. The benefit of using LabVIEW is that it allows for the creation of an easy to use front panel from which the system can be controlled and outputs can be displayed. If applicable it could be easily controlled by community members.
Figure 5: Components of the laboratory scale system. A significant aspect of this project was to source appropriate equipment to fulfil the requirements of the system. (A) Solenoid, used to control the flow rate of the source water stream. (B) Level transmitter, to sense the level of the water in the tank and send continuous signal to the LabJack. (C) Signal conditioner, receives analog signals from sensors and sends analog signal to the solenoid. (D) Conductivity meter, measures the salt concentration of the mixed permeate and source streams. (E) and (F) Permeate and source water mixing vessel, stores the mixed source water and permeate to determine the concentration.
5.0 Methods

5.1 Integration of system components to perform prescribed function

5.1.1 Solenoid

In order for the solenoid to function so that accurate flow rates were produced, it was necessary to calibrate it. The solenoid was calibrated by measuring the volume of water passing through it at one second intervals from 2 seconds to 10 seconds - the results of this process can be seen Figure 6.

![Figure 6: Results from calibrating solenoid.](image)

The equation for the line of best fit from these results as seen in Figure 6 was utilised in an algorithm that relates the time open to a flow rate, see Equation 3 below:

\[ y = mx + c \]

\[ volume = m(time) + c \]

Equation 3

\[ time = \frac{(volume - c)}{m} \]

The next phase in effectively integrating the solenoid into the system was to determine the optimal frequency and duration of the solenoid being open and closed to achieve specified flow rates. By having a higher frequency there is more even mixing of water, however having too high frequency decreases the life of the solenoid (The Solenoid Company 2015) and decreases accuracy of flow...
rates, if it is open for less than two seconds (because the line of best fit does not apply). The algorithm applied to determine the opening and closing duration and frequency is explained in the Appendix B.

5.1.2 LabJack
As the output signal for the level sensor is 4-20mA current and the LabJack is only able to receive voltage signals it was required to place a resistor over two input channels to read the change in voltage from one channel to the other. A 100 ohm resistor was used, this means that the input range is from 400mV to 2000mV.

\[
\text{Ohms Law } \Rightarrow V = IR
\]

\[
4mA \times 100 \, \text{Ohm} = 400mV
\]

\[
20mA \times 100 \, \text{Ohm} = 2000mV
\]

A gain of 10 was selected in LabVIEW, meaning that +/- 2 volts is the range of signal that the LabJack will measure (LabJack 2015). As the analog inputs on the LabJack are 12 bit, it means that the resolution is ~0.98mV and the accuracy of the meter is ~0.73mm. The relationship between the level of water and the output signal is as follows:

\[
1190\, \text{mm} / (1600\, \text{mV}) = 0.74375\, \text{mm/mV}
\]

The grey wires in Figure 7 are responsible for switching the solenoid on and off. LabJack has a number of pre-programmed functions that can be applied. Once the LabJack driver for LabVIEW has been installed it is possible for them to interface. Two different functions were used in this project, these are described in section 5.1.5.1.

Figure 7: Picture from the laboratory showing the wiring required to send and receive signal. Yellow circle highlights the resistor used to convert the current signal to a voltage signal.
5.1.3 Level sensor

5.1.3.1 Calibration

There are a number of considerations for system design that must be taken into account in relation to the level sensor. This particular level sensor comes with a USB adapter that utilises dedicated wires to set the current that is output from the sensor under a number of scenarios. The software “WebCal” must be downloaded from the internet. In this process the primary tasks are to set the range of the sensor and if it outputs 20mA when the level is at its highest or lowest. The settings used in configuring the level sensor are as follows:

Settings:

- 4mA at empty
- 21mA loop fail safe
- 12mA start up
- Calibration
  - Maximum fill height of 6cm from top of tank as this corresponds to the height of the tank overflow outlet
  - Minimum fill height of 119cm (125 - 6cm) as this utilises maximum range of sensor and would correspond to a 50% full tank at field-scale.

Once these settings have been made the actual readings for the voltage were checked by the multimeter and the voltage shown in LabVIEW against the actual height of the liquid. If the real life readings do not match those shown in LabVIEW, the cm/mV reading can be altered, and/or the starting height of the sensors range. It is necessary to check this, otherwise incorrect level readings will result in the program, which in turn would lead to specifying incorrect flow rates.

5.1.3.2 Installation

Physical considerations for installing the level sensor include:

- Installing a standpipe to reduce possibility of interference from the incoming water streams (see Figure 8A, B);
- Drilling an equalisation hole in the dead band so that as the water level rises the pressure can equalise and not impact on the readings that the sensor takes (see Figure 8B);
- Fixing the sensor so that it does not move and is level, ensuring that ultrasound wave is reflecting perpendicular to the surface of the water (see Figure 8C);
5.1.4 Equalisation tank

The tank that was selected had a diameter of 114mm and height of 1300mm. Transparent acrylic material was selected so that the dynamics of the tank would be visible and therefore capable of being compared to the results that are transmitted by the level sensor. A hole has been placed at the 124cm mark to avoid the possibility of water contacting the level sensor and to equalise the pressure in the tank to ambient atmospheric pressure. This means that the total volume of the tank is 12.65L. The volume of the tank has implications for observing and understanding the characteristics of the tank, the smaller the tank the faster the response to level changes. A valve has been installed at the bottom of the tank so water may be released to simulate demand. It was necessary to modify the method for controlling the simulated demand. Initially a needle valve was used, however it was found that this was causing inconsistent flow rates to exit the tank. To overcome this, a clamp was used to reduce the flow through flexible tubing as seen in Figure 8D in the appendix. This method proved to be effective (for further explanation of this issue see Appendix D.

It should be noted that the discharge through the bottom valve is a function of the height of the water in the tank. As the tank empties the elevation head forcing water through the discharge valve...
decreases. Thus, a steady discharge rate was not simulated by this apparatus used for experimentation in this project.

5.1.5 LabVIEW

5.1.5.1 LabJack functions
EAnalogIn, this reads the voltage from one analog input channel. It is necessary to select a differential channel to read the difference between voltages. It is also required to select a gain of 10, this option maximises the resolution of the readings compared to all other ranges available. This function is applied to read the output from the level sensor.

EDigitalOut, this sends 5V signal outputs according to whether a true or false state is wired to it. This function is used to switch the solenoid on and off.

5.1.5.2 Front Panel
The front panel is where the laboratory-scale system is controlled and where its performance is observed. Figures 9 and 10 are screenshots of the front panel that was developed for the laboratory-scale system. In Figure 11 the yellow pane must have all the settings applied before the system starts up, as these controls specify how the inputs are required to be read and where system outputs are to be stored. These are the only controls for the system, the remainder of the front panel are displays of system outputs. In Figure 10 the operational status of the solenoid can be viewed. The flow rate over time of the solenoid is plotted on a graph - the light indicators flash when the solenoid is open (circled in red), and when a new flow rate is computed by the program the time the solenoid is on and off is specified by a numerical indicator (outlined in blue). The purpose of having these indicators and graphs is so that when the system is being run, its performance can be monitored. If unexpected outputs are displayed, it is possible to investigate and rectify these issues.
User specifies from what channel the LabJack is receiving data. Currently set to 0-1.

If there is an error with LabJack connectivity or something else, it will be specified here.

Graphical and numerical display of the water level in the tank.

User specifies what frequency the outputs of water level, and flow rate are logged into Excel.

Figure 9: Screenshot of the front panel for the program used to control the blending process. The yellow outlined area is used in setting up the system.
Figure 10: Screenshot of aspect of the front panel responsible for monitoring the performance of the system. The red circled area monitors the status of the solenoid switching pattern, the blue outlined area displays the precise on/off timings.

5.1.5.3 Block diagram

The block diagram is where the programming takes place, an explanation of how the system is programmed is contained in Appendix C.

5.2 Algorithms for blending strategy

The method for controlling the blending ratio which has been implemented and tested is summarised in Figures 11 and 12. The bottom 14cm of the laboratory-scale tank are below the halfway height of the full-scale tank, if water level is in this region the solenoid is completely open. The next 97cm is the region where there is a linear decrease in flow rate with respect to water level, from 390mL/min to 0mL/min, the remaining 16cm is 0% flow rate. The ratios written inside the tank in Figure 11 roughly correspond to the blended ratio of water entering the tank when the water level is in that region.
Figure 12 shows that each height in the linear range corresponds to a flow rate. The process of utilising the level sensor and tank to convert a water level into a flow rate is as follows:

1. The water level is sent to the LabJack as a current signal, converted to a voltage by the resistor and is conditioned and sent to LabVIEW
2. LabVIEW algorithm converts this voltage to a height, see equation 4:

Equation 4 \( (\text{Voltage reading} - 0.4V) \times 74.375 \left(\frac{\text{cm}}{V}\right) + 7\text{cm} = \text{level of water (cm)} \)

3. The height corresponds to a flow rate, see equation 5:

Equation 5 \( f\text{low rate (mL/min)} = 390 - (4.025 \times (\text{height} - 14)) \)

4. Flow rate corresponds to the amount of the solenoid required to be open, see equation 6:

Equation 6 \( \text{time} = \frac{(\text{volume} - c)}{m} \)

From \( y = mx + c \)

With, \( m = \text{gradient} \)
\( c = \text{y-intercept} \)
5.3 Experimental procedures

5.3.1 Effect of temperature on solenoid flow rates
The purpose of this test is to determine whether the flow rate is affected with a change in temperature of the water. Application of this system is likely to be in climates that reach high temperatures where devices such as solenoids can reach up to 60°C. The laboratory-scale system was tested to see whether it is affected by temperature and if necessary a method to compensate for these changes could be applied and therefore potentially adapted to the full-scale system.

Flow through the solenoid was measured at three different temperatures: 25°C, 42.5°C and 60°C. The water reservoir that the pump was pumping from had an in-built heating element that allowed for programmable temperatures. Once the set-point temperature was reached the flow rate testing could begin. To test flow rate, water flowing through the solenoid was captured in a measuring cylinder at three seconds, five seconds and ten seconds - repeating three times. In order for the duration of time water is being captured to be accurate, the solenoid was programmed to open for the required length of time. It was ensured that the height of the outlet point for where measurements were taken from was the same as where it will be in the system, as a change in head will change flow rates.

5.3.2 Testing accuracy of system parameters

5.3.2.1 RWB flow rates
It was necessary to test the accuracy of the RWB flow rate because it is the main controllable variable in the whole system, it affects salinity and the level of water in the tank. It is important to have this variable accurately controlled so that the results provide a true representation of the dynamics of the laboratory scale system. This testing also demonstrates how accurately the solenoid has been calibrated, and the effectiveness of the algorithm that controls flow rates through the solenoid. Starting from the low range of the flow rates, up to the high, in random size increments averaging about 30mL/min were put into the program for the solenoid to control. The value that was input in the program was then compared against the measured volume of water collected over a minute.

5.3.2.1 Water level in equalisation tank
The water level that is sensed in the tank is data that is feedback to the system and used to inform the flow rate of the solenoid. The primary possible sources of error are, if the level sensor is not calibrated properly, the voltage signal will give incorrect values for the height of water in the tank, and if the conversion of voltage to height in the LabVIEW block diagram is incorrect. The accuracy of
the level sensor was tested by filling the tank and then releasing a random volume of water, measuring the height of the level of water at this point with a measuring tape and comparing to the value displayed in the LabVIEW program. This was repeated until the tank was empty.

5.3.3 Response of system to simulated demand conditions

A major requirement to prove that the simulation system is meeting the project objectives is to observe how the blending strategy responds to scenarios of demand at specific tank levels. It is particularly important to determine how it performs in situations where it would be most likely to fail, in other words, to monitor performance during the most challenging response scenarios.

Example situations are when the tank will most likely overfill, resulting in the RO needing to switch off, and when the water level in the tank goes below 50% (110cm), resulting in a potential dry tank outcome. A number of tests were run to simulate these conditions, in each of them the response in concentration of water entering the tank, the flow rate of the bypass stream and the level of the tank were measured. The flow rate of the water exiting the tank was also measured periodically by the bucket and stopwatch method.

Tap water with a concentration of approximately 200 ppm TDS was used to simulate the permeate stream and the RWB stream had sodium chloride added to it so that a concentration of 1500 ppm TDS would be achieved. This range was selected as it is close to what is expected for full-scale application.

**Experiment 1: Filling of tank with low demand (supply exceeds demand)**

At the end of the day it is likely that the tank will be at its lowest and will then refill overnight. Due to remote communities often having leaks it is probable that there will not be zero demand during the night time period. This test demonstrated the filling of the tank from empty to full with a constant low demand. The demand was set to 48mL/min at 9.5cm from the bottom of the tank.

**Experiment 2: Constant high demand from full tank (demand exceeds supply)**

It is possible that this scenario would occur during the morning. After the night time period when the demand is low, the tank is able to fill up, and when community members wake up the demand sharply increases. In order to simulate this scenario the tank was filled to the top, with water released at a flow rate equal to the maximum output for the permeate and bypass streams combined (440mL/min).
Experiment 3: Incrementally increase demand (steadily increasing demand)

This scenario simulates the time it takes to reach steady state when incrementally increasing demand. The experiment begins with the tank at mid-way (60cm), with a low flow rate (demand) at the bottom of the tank (56mL/min). When the level stabilises the flow rate is increased again, repeating this process until the tank is empty.

Experiment 4: High demand to low demand (switch from high to low)

This scenario simulates the sharp transition from high demand in the evening to low demand at night (emptying tank to filling tank). The valve at the bottom of the tank is set to a high demand and once it reaches steady state near the bottom of the tank, the flow rate is then adjusted to a much lower level, allowing the tank to refill.

6.0 Results and Discussion

6.1 Effect of temperature on solenoid flow rates

The results of the effect on flow rate with changing water temperature can be seen in Table 4. Converting the results for the volume of water captured over ten seconds into a flow rate of L/min results in a difference in flow rate of 6mL/min, or 1.48%. This difference in flow rate is not significant enough to warrant making changes to the system to compensate for it such as, calibrating the solenoid for higher temperatures.

It is possible for the flow rate through valves to be affected when an increase in temperature of water occurs, this generally results in the flow rate increasing. The implications for an increase in flow rate would be that the response to the level of water in the tank would be faster than expected and ultimately fill the tank faster. In order to nullify this effect the solenoid would be recalibrated so that the flow rate that passes through it would be controlled as desired. The same method used for calibrating the solenoid may be applied, repeating at specified temperatures up to 60°C. After obtaining these results a plot of the different flow rates against time of solenoid being open may be created and a relationship obtained. This equation would then be applied to determine the length of time the solenoid must be open at a given temperature to achieve a specified flow rate.

Measurement devices such as conductivity meters and ultrasonic level transmitters can also be affected by temperature. Both the conductivity meter and level transmitter used in the laboratory-scale system have in-built sensors and programming to compensate for the effect of temperature. Despite the laboratory-scale system not show a significant change in flow rate due to an increased
temperature, the field-scale system should still be tested to see how it is affected. The field-scale system will utilise different equipment that may respond differently to an increased temperature and therefore should be tested before commissioning.

Table 4: Change of volume for RWB stream with increasing temperature.

<table>
<thead>
<tr>
<th></th>
<th>25°C (ambient)</th>
<th>42.5°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three seconds</td>
<td>22mL</td>
<td>21.5 mL</td>
<td>21 mL</td>
</tr>
<tr>
<td>Five seconds</td>
<td>35 mL</td>
<td>34.5 mL</td>
<td>34.25 mL</td>
</tr>
<tr>
<td>Ten seconds</td>
<td>68 mL</td>
<td>67 mL</td>
<td>67 mL</td>
</tr>
</tbody>
</table>

6.2 Response of system to simulated demand conditions

Experiment 1: Filling of tank with low demand (supply exceeds demand)

The extreme case scenario simulates where the demand has been very high for a long period and then transitions to medium to low flow range (48mL/min at base of tank). The results are shown in Figure 13 and 14. As expected the tank initially fills up quickly and as the combined SP and RWB flow rates become close to equalling the demand, the tank level approaches steady state. In Figure 13 the water level in the tank starts at 7cm, this is because the level sensor is incapable of sensing beyond this point, the tank reaches a final steady height 107.5cm. Therefore, if the flow rates of the SP and RWB are what they should be (55.7mL/min 13.47mL/min respectively) the flow rate out of the tank would be 69mL/min.

It would have been useful to test how this system responds under assumed water usage patterns looking at the transition from high night time usage when the tank is at its lowest point, to lowest usage, which is during the night. This is a critical period of time where the blending strategy must control the flow rate of the RWB so that the tank does not reach 100% capacity as this is the condition that requires the RO to shut off. This experiment would observe the time taken to reach

![Figure 13: Response of water level in tank to low demand scenario – level maintained below 100%](image1.png)

![Figure 14: Response of flow rate to height in tank during low demand scenario](image2.png)
capacity with a constant demand of 10.5mL/min which corresponds to the assumed leakage rate.

**Experiment 2: Constant high demand from full tank (demand exceeds supply)**

Applying the assumed demand profile it would be possible to estimate the capacity of the tank at its lowest point. The time taken for the tank to rise from this level to 100% capacity would be observed and the results would be compared to the time scale of the field-scale system. If the time taken to reach capacity is longer than the beginning of the increased morning demand then the blending strategy would be successful in allowing the RO unit to run continuously. If not, and it reaches capacity before this time the blending strategy would need to be altered so that the range at which zero flow rate RWB is initiated is increased to correspond to a depth further down the tank to ensure continuous RO operation is possible. The algorithm for the linear response to height of the tank would also need to be altered slightly.

As expected, when the tank is full and there is high demand, the rate at which it empties will be high at first and then reduce as can be seen in Figure 15. There are two reasons for the slower approach to steady state. Firstly, the response to high demand when the water level is high, is slow because the algorithm does not respond to rates, only the height – so at high levels in the tank the bypass flow rate is low. When the water level is lower the bypass flow rate increases and the difference between the demand flow rate and the bypass flow rate is less, therefore decreasing the rate of change of water level in the tank. Also higher levels in the tank correspond to higher flow rates out of the tank due to the higher head that exists. Figure 16 shows all three flow rates of the different water streams entering and exiting the tank to produce the resulting water levels as shown in Figure 15.

Ideally in communities that have water supplied by header tank, the difference in head from the top of the tank to the bottom does not significantly affect the flow rate they receive. This is because this difference in head is small compared to the absolute head of the system. What this means, is that the full-scale system would not have the flow rate of the tank significantly change as a function of water elevation in the tank.

Figure 17 shows the salinity concentration over time, the salinity rises steeply initially due to the high flow rates of the bypass stream that has a high concentration of 1.5ppt. As the flow rate of the bypass decreases so does the rate in increase of the salinity concentration. A maximum of 1.485ppt occurs at the 21 minute mark. It is unexpected that a concentration this high occurred, if the flow rates into the tank were what was expected (55.7mL/min for permeate and 390mL/min for bypass) the maximum concentration would have occurred and thereafter remained steady at 1335 ppm. The
conductivity results therefore show that ratio of bypass to permeate is actually higher than 7:1, the suspected cause for this is explained in Section 6.2.

![Graph showing tank level response](image1)

**Figure 15:** Response in tank level under high demand scenario – level maintained at 50%.

![Graph showing flow rates](image2)

**Figure 16:** Flow rates for SP, RWB and simulated demand under high demand scenario.
Figure 17: TDS concentration of mixed SP and RWB time under high demand scenario.

**Experiment 3: Incrementally increase demand (steadily increasing demand)**

The effect of step changes of 138mL/min to 173mL/min at the 27 minute mark and from 173mL/min to 230mL/min at the 54 minute mark on tank water level can be seen in Figure 18. Had this experiment been done so that the step change was increasing with equal increments then it would have been possible to see that as the level in the tank gets lower, steady state will be reached faster due to the increased RWB flow rate and decreased simulated demand due to less head. This effect would occur on the field-scale system also, except the rate would be less affected by a change in head.

Figure 18: Tank water level response to stepped demand increase after reaching steady state. Red line shows the time when step changes occurred.
Experiment 4: High demand to low demand (switch from high to low)

In Figures 19 and 20 it can be seen that a long period of high demand has been simulated as evidenced by the low level of water in the tank and the steady state that has been reached at this point. The demand is instantaneously reduced, as shown by the sharp increase in the level of water in the tank. This sharp switch in demand would not occur in a real life application, as this would require all water use in the community to simultaneously stop. However what these results show is that the system is capable of switching from a high demand to a low demand and then reaching a steady state. The response of the TDS concentration to the RWB flow rate and its relation to tank height is what is expected. The TDS concentration is at its highest point when the tank level is lowest and BRW flow rate is highest. As the tank level rises the RWB flow rate drops off and so does the TDS concentration.

![Figure 19: Response of bypass flow rate with switch from high demand to low demand.](image)

![Figure 20: Response of tank water level and TDS concentration of blended stream entering tank with switch from high to low demand.](image)
6.3 Accuracy of system parameters

The discrepancies between the measured concentration of the blended water entering the equalisation tank and the theoretical concentration of at specific point in time with expected flow rates in Experiment 1 demonstrates that one or both the flow rates of the RWB and SP streams are not what they should be (see Figures 20 and 21).

The results from Experiment 4 do not support this level of inaccuracy, in Figure 23 it shows that the RWB has a flow rate of 71mL/min and has a recorded simulated demand of 122mL/min, therefore the calculated flow rate of SP would be 51mL/min. However during this experiment the centrifugal pump was replaced with a peristaltic pump for the SP stream, due to suspected inconsistent flow rates. The peristaltic pump is capable of programming flow rates accurate to 0.1mL/min and the flow rate was tested immediately before this experiment; therefore it is more likely that the RWB stream was the cause of the error in this circumstance. The results from Experiment 1 were obtained using a centrifugal pump for both the RWB and SP, so if it was the centrifugal pump that was the cause for the discrepancies in calculated concentration then it would explain the increased error for this test.

The issue of inconsistent flow rates was recognised early on in the project. It was thought that this issue had been overcome by installing a bypass, however these results do not support this; further explanation on identifying and resolving this issue are explained in Appendix D. During the development of the laboratory-scale system, key components requiring accurate control and measurement were tested for their accuracy, the results can be seen in the following section.

6.3.1 Accuracy of RWB flow rates

Table 5 shows that across the whole flow rate range, the measured flow rate is lower than the programmed flow rate as set by the program. Lower flow rates than expected as shown in Table 4 will reduce the rate at which the system reaches steady state, and also lower the height of the steady state. If one pump has slowed more than the other it will also impact on the blended concentration of the water entering the tank. The cause of consistently lower flow rates than the programmed values is believed to be due to the decreased output of the centrifugal pump over time. These results therefore support the reasoning that reduced flow rates have caused the blended TDS concentration in Experiment 2 to be higher than expected. Appendix D further explains the issues that were experienced on decreasing output from the centrifugal pump and the methods used to overcome this. It was thought that methods used to overcome this issue were sufficient however the results in this accuracy test and those of the experiments contained in the discussion demonstrate that it was not, it is therefore proposed that a peristaltic pump is trialled as a
replacement to overcome the inconsistent flow rate issue. In conclusion, the inaccuracies experienced for the RWB are not due to the calibration and programming that have been applied. Further testing using the peristaltic pump as a replacement may confirm this.

Table 5: Comparison of the programmed and measured flow rates of the RWB stream

<table>
<thead>
<tr>
<th>Programmed flow rate (mL/min)</th>
<th>Measured flow rate (mL/min)</th>
<th>% difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10</td>
<td>0.0</td>
</tr>
<tr>
<td>15</td>
<td>13</td>
<td>13.3</td>
</tr>
<tr>
<td>20</td>
<td>19</td>
<td>5.3</td>
</tr>
<tr>
<td>30</td>
<td>28</td>
<td>7.1</td>
</tr>
<tr>
<td>50</td>
<td>49</td>
<td>2.0</td>
</tr>
<tr>
<td>65</td>
<td>62</td>
<td>4.8</td>
</tr>
<tr>
<td>80</td>
<td>82</td>
<td>-2.4</td>
</tr>
<tr>
<td>100</td>
<td>97</td>
<td>3.1</td>
</tr>
<tr>
<td>130</td>
<td>130</td>
<td>0.0</td>
</tr>
<tr>
<td>165</td>
<td>159</td>
<td>3.8</td>
</tr>
<tr>
<td>190</td>
<td>190</td>
<td>0.0</td>
</tr>
<tr>
<td>210</td>
<td>202</td>
<td>4.0</td>
</tr>
<tr>
<td>245</td>
<td>237</td>
<td>3.4</td>
</tr>
<tr>
<td>275</td>
<td>262</td>
<td>5.0</td>
</tr>
<tr>
<td>300</td>
<td>288</td>
<td>4.2</td>
</tr>
<tr>
<td>350</td>
<td>335</td>
<td>4.5</td>
</tr>
<tr>
<td>390</td>
<td>365</td>
<td>6.8</td>
</tr>
</tbody>
</table>

6.3.2 Accuracy of water level in the tank

Table 6 shows the results of comparing the physical measured height of water in the tank against that measured by the level sensor and converted to a height as per the algorithm contained in the program that has been developed. There is a somewhat even occurrence of negative and positive differences between the two as shown in the third column. This indicates there is no systematic cause for the inaccuracies, the magnitude of the inaccuracies are also so small that they are insignificant relative to system functionality. It is likely that they result from a noisy signal, this may
be remedied by conditioning the signal, by adding a moving average or some other strategy in the program.

Table 6: Comparison of sensed and calculated height compared to physical measured

<table>
<thead>
<tr>
<th>Sensed and calculated height (cm)</th>
<th>Measured height (cm)</th>
<th>% difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>119.2</td>
<td>119.1</td>
<td>-0.08</td>
</tr>
<tr>
<td>112.9</td>
<td>113.1</td>
<td>0.18</td>
</tr>
<tr>
<td>105.3</td>
<td>105.7</td>
<td>0.31</td>
</tr>
<tr>
<td>101.3</td>
<td>101.6</td>
<td>0.30</td>
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<tr>
<td>94.3</td>
<td>94.4</td>
<td>0.11</td>
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<tr>
<td>87.5</td>
<td>88</td>
<td>0.57</td>
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<tr>
<td>77.9</td>
<td>78.15</td>
<td>0.32</td>
</tr>
<tr>
<td>68.9</td>
<td>68.8</td>
<td>-0.15</td>
</tr>
<tr>
<td>60.4</td>
<td>60.1</td>
<td>-0.50</td>
</tr>
<tr>
<td>52.3</td>
<td>52.3</td>
<td>0.00</td>
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<tr>
<td>37.9</td>
<td>37.6</td>
<td>-0.79</td>
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<tr>
<td>24.5</td>
<td>24.8</td>
<td>1.22</td>
</tr>
<tr>
<td>17.9</td>
<td>18.3</td>
<td>1.95</td>
</tr>
<tr>
<td>9.6</td>
<td>9.5</td>
<td>-1.04</td>
</tr>
</tbody>
</table>

### 6.3.3 Summary of inaccuracies

Throughout the project there have been many components that performed in an unexpected manner, subsequently causing results that were not consistent with what was expected. This required investigation to determine the issue and trial and error to test solutions to these issues. Due to time constraints it was not possible to remedy all of these issues. For the most part the results obtained are adequate in demonstrating the dynamics of system response to the blending strategy. Future work, however, would ideally repeat these experiments with a peristaltic pump for both the RWB and SP streams to obtain results that can be accurately translated to the full scale system.
6.4 Implications of blending strategy on water quality

The major objective with any water treatment system is to bring the water quality to a level that is desirable for its end use. With this in mind it must be evaluated whether the blending strategy that was proposed in this system will allow the water treated and stored to be of a salinity acceptable for the use by the community. The level of TDS concentration that is deemed acceptable is subjective, and therefore as the Australian Drinking Water Guidelines (ADWG) states it’s important that the community will accept the level of treatment provided (NHMRC 2011). So a significant aspect in assessing the appropriateness of this blending strategy is whether the salinity of the water produced is in an acceptable range for the case study communities. The ADWG specifies that a TDS less than 600mg/L is regarded as good quality drinking water and that above 1200mg/L is regarded as unacceptable (NHMRC 2011).

According to the assumed water use profile shown in Figure 1 against which the blending strategy is being assessed the blending strategy against, the peak average demand (between 6:00am and 10:00pm) is approximately 1800L/hr. Blended water at this rate corresponds to a 4:1 ratio. This, however is not likely the average blending ratio that will be produced during this period, as the RWB flow rate is not directly a function of demand, it is rather, a function of the tank height which is related to demand. It is therefore anticipated that this relationship results in a delayed response of RWB flow rate to demand and therefore higher flow rates will continue slightly longer after the peak period. This also means that lower flows and therefore higher quality will continue into the beginning phase of the morning peak period, resulting in the morning period experiencing the highest quality water and the late evening the worst. It is therefore anticipated with the assumed demand profile that the water received by members of the community will fluctuate between 2:1 and 4:1 blends which equates to 800 – 960 mg/L TDS. This, is in the fair range for palatability (NHMRC 2011). If desired by the community, and economically feasible it is possible to increase the quality of water that the users receive by increasing the RO capacity. It is easy to increase RO capacity as it will not impact on the configuration of the overall system.

The quality of water can also be improved further by reducing leaks, with the assumptions made that leaks contribute to 10% of the total daily load. By reducing leaks less water exits the tank, which means the level can be maintained at a higher position throughout the day resulting lower flow rates of RWB. It is also possible that this blending strategy could positively influence the behaviour of the users and their values toward water conservation. If community members are aware that using unnecessary quantities of water will reduce the quality of water that they are drinking then it is
possible that more importance will be placed in conserving it – this may require education and evaluation.

Further testing involving the control of the flow rate out of the tank according to the assumed water use profile would give a much better representation of the expected impact on the tank level and quality of water entering the tank at different times of the day. This could be plotted against the water use profile providing useful visualisation of how demand, water level and quality are related and impact on each other. This would test the blending strategy performance over the day and help to identify how the blending strategy may be optimised to increase water quality. It may be possible to control the flow rate exiting the tank by attaching a peristaltic pump that is capable of delivering the flow rate programmed over a period of time.

The outcome of the treatment and blending process is the quality of water that the users are receiving, which is therefore the salinity in the equalisation tank. If optimising of water quality is to take place it will be necessary to monitor this variable. This could be achieved by having a conductivity sensor set-up in a manner similar to that which has been used for water entering this project, this may also be coupled with an algorithm in LabVIEW that is capable of predicting the concentration of blended stream entering the tank.

**6.5 Appropriateness of the blending strategy under different scenarios**

**6.5.1 Changing community size**

It may be useful to test how the quality of water entering the tank is affected with an increase and decrease in community size. In these experiments the demand would increase and decrease accordingly, with the effect on water quality and the rate at which the system reaches 100% capacity being observed. As remote Aboriginal community populations are known to fluctuate significantly, these experiments would be useful to test the robustness of the blending strategy under these scenarios, so that methods to overcome any observed problems may be developed.

**6.5.2 More water required for irrigation**

If the community uses large volumes of water from the blending tank for irrigation, the water used for irrigation may be much higher quality than required and drinking water may be much lower quality - approaching unpalatable status. Therefore, if irrigation does represent a significant component of total use, it is recommended that there is either a separate tank for the collection of untreated irrigation water or a different water blending strategy is applied that is capable of delivering lower quality water during periods of high irrigation use, whilst maintaining higher quality water during periods with high demand for other purposes.
6.5.3  High level of dilution required due to high contaminant concentration

In situations requiring greater proportions of permeate due to high contaminant concentrations such as nitrate or uranium, the current blending strategy would be insufficient. If this lower blending ratio is used for all water use purposes then the effectiveness of this blending strategy will be significantly reduced. Perhaps a better method would involve treating water to high levels for drinking purposes and maintaining the standard blending strategy for the rest of the water uses.

It is also possible for the quality of the source water to change over time due to increasing salinity or contamination issues which are known to occur in remote communities. It is therefore important that the water being extracted from the bore is tested to check this. If the quality decreases significantly it may be necessary to change the blending strategy to allow for increased permeate inflow or install another RO unit.

6.6  Options to improve the tested blending strategy

For the three scenarios described in Section 6.5 it is likely that blending strategy applied in this project will need to be altered or changed, some suggestions for how these changes could be made are as follows.

6.6.1  Proportional controller

One of the shortfalls of the blending strategy proposed applied in this project is that it does not optimise the quality of water entering the tank. This is because the strategy only uses the instantaneous water level to determine the flow rate, so regardless of whether the tank is in a mode of rising or falling the same RWB flow rate will occur. In order to optimise the quality of water entering the tank, a proportional controller could be applied, this will use the rate of the tank’s change in height as well as the actual height to determine the RWB flow rate. For example if it senses that the rate the tank is increasing quickly, it means that the inflow is high in relation to the demand, by slowing the RWB flow rate it increases the ratio of permeate and thereby increases the quality of water in the tank.

6.6.2  Reduce recovery ratio to utilise brine

In situations where the salinity of the source water is high and impacting on livestock or gardens, it may be possible to reduce the recovery ratio of the permeate so that the salinity of the brine is reduced to a level that is usable. In doing this it provides a method for the brine to be used and is no longer a burden to be disposed of. It may also be possible to use the reject stream for washing, cleaning and toilet flushing (Richards and Schafer 2002), however it is likely that this will require extra plumbing which adds complexity to the system and would come at an extra cost to install. In
assessing the suitability of this practice it would be necessary to determine how this may negatively impact on the receiving environment, such as reducing soil fertility and increasing the salinity of groundwater.

6.6.3 Blending strategy utilising cascade control process

This method involves blending water after the two streams of SP and RWB have been stored instead of using the level of water in the tank to control the RWB flow rate, a conductivity meter is used to measure the blended stream concentration with the flow rate of the SP stream adjusted to maintain this setpoint. Figure 21 shows a simplified configuration of such a system.

This method is advantageous, due to its ability to directly control the concentration of the water that the community uses. However, it is likely that an electronic proportional valve will be required to control the flow rate of water exiting the RWB tank because a solenoid would result in pulses of high quality water and lower quality water.

In situations where it necessary to separate high quality blended water from lower quality water (such as when drinking water is required where there is high concentrations of nitrate in the source water), it may possible to use a timer that blends all water produced at a certain time over specified duration to a higher quality. The community is then able to store this high quality water for the day to drink from, while for the rest of the day the usual blending strategy is resumed. This may be advantageous compared to adding another RO unit and treating all of the water that is used to a higher level, as would be required if the water quality improvement was to be achieved with the blending strategy tested in this project.

Figure 21: Simplified PID of cascade control process.
6.7 Field-scale application

This project has focused only on the blending component of the whole water supply system described in Figure 3 and is based off a scenario that assumes a tank of 220 000L is available, the water source quality does not deviate much from what has been recorded, there are methods to deal with brine and there is a constant power source is available. These factors and many others will come into play when implementing this system at field-scale. It is therefore necessary in future steps that assess the viability of this system to have a more in depth understanding of the existing community infrastructure and begin to look at the rest of the system to determine whether any compromises or changes to the blending strategy will be required to be made. For example, if it is not possible to use a tank that has a capacity as large as 220000L then this will change the dynamics of the tank, it will respond faster to water level changes and have a lower residence time meaning the salinity will fluctuate faster. Also a header tank may not be available, which reduces the buffer of water available to the tank – it may be necessary to consider optimising energy consumption of the pump in relation to the blending strategy and the timing at which blending takes place. Importantly, through this process the economics must be considered as this often has an implication on all aspects of design.

The program and algorithms that have been developed for the field-scale system are capable of being translated to the field-scale system. The algorithm used to convert the level water to a flow rate through the solenoid can be used, with slight alterations made if the tank height is different. Also the algorithm used to determine frequency and duration of the solenoid opening and closing to achieve specified flow rates can be used, but it is advised that some alterations are made. This algorithm can result in the number of times the solenoid cycles per minute being up to 25. The purpose of having the number of cycles so high in the lab-scale version was to ensure that the flow rate per minute was accurate otherwise the actual bypass flow rate response would result in steep jumps in level of the tank with the level rising and falling significantly between on/off cycles due to the volume of the tank being so small. However, in the full-scale system it will be possible to a lower number of cycles, with the control of flow rates being accurate on a per hour basis rather than a per minute basis. Doing this will likely increase the life time of the solenoid.

6.8 Summary of future work

A number of areas have been identified for future work that will assist in the affective progression from laboratory to field scale application.
6.8.1 Further testing on the current strategy and system
As prescribed in section 6.3.3 there is some further testing that can be done to more accurately determine the dynamics of the system, this would improve the accuracy in which these results can be related to the full-scale system. This may also include maintenance on the flow meter so that it can be incorporated in the system, allowing for the accuracy of results to be checked.

6.8.2 Obtain further information from the case study communities

6.8.2.1 Community needs assessment
A survey on what the community believes the issues with their water supply system are, their water use habits, desired water quality and ideas for solutions. This information will inform the objectives and design of the system.

6.8.2.2 Water audit
A water audit of the community would provide a more accurate understanding of the water used by the community. This will enable the identification of leaks and make it possible to obtain a more representative water use profile that could then be tested on the laboratory-scale model to determine the performance of the blending strategy. Information obtained from these experiments would then be able to be used to optimise the strategy to allow for higher quality blended water.

6.8.2.3 Existing community infrastructure assessment
This would involve conducting an investigation into what the water supply system consists of, such as the volume of header tanks and the pressure they deliver, type of energy supply, pump specifications, water treatment technology, etc. Paying particular attention to the quality of the existing infrastructure, i.e. whether there are leaking pipes, pump is faulty. This kind of information is useful to take account in the economic assessment.

6.8.2.4 Study other remote communities requiring water treatment
In order for the automated blending concept to be applicable to other remote communities, it is necessary to consider the variety of conditions and specific requirements that they may have. For example, other communities may have water quality issues with different parameters than those of the case study sites, such as organics and microorganisms. This may bring about the need to alter the blending strategy or add additional components. In the case of microorganism contamination it may be necessary to include a disinfection unit before the RO unit so that the RWB does not contaminate the permeate once blended. Future work could investigate the range of contaminants that would be expected to be encountered in remote communities and how the system may need to be altered to allow for appropriate treatment.
6.8.3 Development and testing of improved blending strategies
This would first involve further investigating the water supply needs that arise from the scenarios listed in Section 6.5 (and possibly others), and how they impact the suitability of the blending strategy employed in this project. After a more comprehensive identification of water supply requirements and the shortfalls of the current system in meeting them, the ideas for the proposed improved blending strategies from section 6.6 (and possible others) may then be further developed and tested.

6.8.4 Investigate factors in the up-scaling of the automated blending system
Once an understanding of the existing infrastructure has been gained it will then be possible to work on designing for the practicalities in applying the blending concept at field scale. Some examples for the kind of work required are as follows:

- Investigating appropriate energy sources;
- Investigating brine management options;
- Determining the capital cost for an upgrade;
- Determining maintenance requirements and costs.

6.8.5 Develop education program
Create an education program that can allow the community to successfully utilise the new water treatment and supply system. This would involve explaining how the system works, how their water use behaviour influences the water quality of the system and how they can be involved in maintaining the system.
7.0 Conclusion

A laboratory-scale system was developed to simulate a blending process that may be applied for the supply of treated water in remote communities. Successful application in the laboratory-scaled system of hardware components, such as the level sensor, and software components, such as the blending strategy, may be translated to field-scale. The blending strategy which was applied demonstrated that it is capable of maintaining steady states and with the exception of extreme cases, is capable of maintaining continuous operation of the reverse osmosis unit, whilst also maintaining the level of water in the tank above 50%, thereby demonstrating that the proposed field-scale system can achieve its aims. Further work to optimise the quality of water stored in the tank and potential methods to achieve this have been identified. Based on the initial groundwork in developing a physical laboratory-scale blending system it is envisaged that this blending strategy has potential to address water quality and scarcity issues and potentially increase the accessibility of water treatment systems to remote communities. Future work that explores the case specific application of the proposed blending process will provide a means to assess the true potential in achieving these aims.
References

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Appendices

Appendix A: Summary of equipment and costs

The equipment used for the laboratory scale system and their price is summarised in table 7. Many of these prices are not indicative of what would be costed for a full scale system since they were procured in small quantity lots.

Table 4: Summary of equipment used for laboratory scale system

<table>
<thead>
<tr>
<th>Equipment name</th>
<th>Purpose</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>LabJack U12 series</td>
<td>Receive data from sensors and send signal to control instruments</td>
<td>$194</td>
</tr>
<tr>
<td>Flow meter (FLR1008)</td>
<td>Measure the flow rate of the permeate</td>
<td>$415.5</td>
</tr>
<tr>
<td>Acrylic pipe</td>
<td>This will act as an equalisation tank</td>
<td>$258.5</td>
</tr>
<tr>
<td>Level transmitter</td>
<td>Send level signal</td>
<td>$642</td>
</tr>
<tr>
<td>Solenoid</td>
<td>Control water flow</td>
<td>$0, donated by Dr. Cord-Ruwisch</td>
</tr>
<tr>
<td>Switch for solenoid</td>
<td>Open and close solenoid via electronic signal</td>
<td>~$20</td>
</tr>
<tr>
<td>Replacement solenoid</td>
<td></td>
<td>$165</td>
</tr>
<tr>
<td>Gate valve</td>
<td>Reduce flow rate for bypass line that return to tank</td>
<td></td>
</tr>
<tr>
<td>Needle valve</td>
<td>Control simulated permeate stream phase 1 &amp; fine control for bypass line that return to tank</td>
<td></td>
</tr>
<tr>
<td>Centrifugal pump</td>
<td>Pump source water stream</td>
<td></td>
</tr>
<tr>
<td>Peristaltic pump</td>
<td>Pump for simulated permeate stream</td>
<td></td>
</tr>
<tr>
<td>Frame</td>
<td>Allows for all system components to be move and stored as one unit</td>
<td>~$100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>~$1650</td>
</tr>
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</table>
Appendix B: Algorithm for controlling flow rate through solenoid

This section explains how the LabVIEW program calculates the open and closed duration and frequency to achieve specified flow rates (read while observing LabVIEW program):

In order to determine what frequency and how long the solenoid must be open, two factors are taken into account:

- The amount of time open to achieve specified flow rate
  - This is determined by the equation for the calibration line
- Frequency of on and off
  - Higher frequency = more even mixing
  - Too high means that it is less accurate (below 2 seconds) as it is non-linear

Five different scenarios based off the duration the solenoid is open for were developed to control flow rates to precise quantities in units of (mL/min), see below:

1. 0-28 mL/min
   - Solenoid opens for 1 block of time them stays shut for remainder of minute
2. 28-279 mL/min
   - Solenoid opens in blocks of approximately 3 sec
3. 280-346 mL/min
   - Solenoid opens for blocks of approximately 5 seconds
4. 346-385 mL/min
   - Solenoid opens for blocks of approximately 5 seconds
5. 386-390 mL/min
   - Solenoid stays open for one block of time and stays shut for remainder of minute

The algorithm used for determining the on and off duration and frequency:

1) Total time on/(solenoid opening  block of time) = number of blocks required rounded to lowest denominator

2) 60 sec – rounded total time on = rounded total time off

3) Rounded total time off / number of blocks required to round to lowest denominator

4) Time off / number of blocks required rounded to lowest denominator
5) Remainder from (1) x (time on) / number of blocks required rounded to lowest denominator

6) (3) − (4) = time required each OFF interval

Example of the above algorithm

240.5mL/min is the required flow rate

The required time on as determined by the calibration of the solenoid:

\[ y = 6.4375x + 1.9028 \]

\[ time = \frac{(volume - c)}{m} \]

\[ time = \frac{(240.5 - 1.9028)}{6.4375} = 37.07 \text{ seconds} \]

Using equation, total time ON = 37.07 seconds

\[ 37.07 \div 3 = 12.36 \sim 12 \text{ blocks} \]

Total rounded time off

\[ 60 - 36 = 24 \text{ sec} \]

Rounded OFF block time

\[ 24 \div 12 = 2 \text{ sec} \]

Subtracted time from rounded OFF interval

\[ ((12.36 - 12) \times 3) \div 12 = 0.08925 \]

Time for OFF interval

\[ 2 - 0.08925 = 1.91075 \text{ sec} \]
Time for ON interval

\[ 37.07 \div 12 = 3.0892 \text{ sec} \]

Check to see whether calculated On/Off intervals correct

\[ (12 \times 3.0892) + (12 \times 1.91075) = 60 \text{ sec} \]
Appendix C: LabVIEW code

The outcomes of this program are to switch the solenoid on and off according to the height in the tank, display certain characteristics of system performance on the front panel and send data to excel. Figure 22 shows the code that is required to export the level of water in the tank and the calculated RWB to excel. It was essential to have this functionality in the program so that the results of the experiment could be viewed later and analysed.

The process in which the program obtains data and manages it to fulfil the outcomes is explained. A voltage reading from the LabJack is received via the LJ EAI function, this value is then converted into a height via the numbers that are connected to this function and also as shown in equation 4 in the main body of this report. This value is then displayed as a tank level on the front panel and is also sent to the case structure above it. Depending on what the level is there will be different case for how to respond to the tank level. For below 14 the maximum flow rate of 390 is sent, for 14 – 110 as shown in the Figure 23 the level is converted into a flow rate as per equation 5 and for 111-119 the flow rate is 0.

The value that exits this case structure is converted to a total time that the solenoid must be open to achieve this flow rate as per equation 6 which was obtained from calibrating the solenoid. This value then enters another case structure, the range of the number will determine the case. This number is then input to an algorithm that calculates the amount of time on and off to achieve a precise mL/min flow rate (this process is described in Appendix B). Inside all of the cases is a sequence that is responsible for switching the solenoid on off by using the LJ EDO function. This function tells the solenoid to switch on in the first frame of the sequence, the second from then specifies how long the solenoid is on for which is determined by the algorithm. After this period of time the solenoid is switched off and maintained for period of time as determined by the algorithm. Once this has been completed the whole loop begins again, with a new voltage reading being taken.
Figure 22: Screenshot of LabVIEW code responsible for exporting data to excel

Figure 23: Screenshot of one half of the loop where the signal of the level sensor is received and the solenoid is controlled.
Figure 24: Screenshot of the other half of the loop where the signal of the level sensor is received and the solenoid is controlled. The sequence for switching of the solenoid can be seen, as well as the algorithm as described in Appendix B.
Appendix D: Inconsistent flow rates for permeate and source water streams

It was observed that the flow rate of permeate as well as the feed water were inconsistent. This would be an issue because theoretical output would not match actual output resulting in unexpected blending concentration and system dynamics - it was uncertain what was causing this. A process of trial and error for in finding the source for the decrease in flow rate took place.

These pumps have been used before for higher flow rates and a decrease in flow rate was not reported. This observation was tested and confirmed, the results can be seen in Figure 25.

![Figure 25: Flow rate of the centrifugal pump with no restriction of flow.](image)

The flow rates required for this project (25-700mL/min), so it was likely that this lower flow rate was somehow causing inconsistent flow rates. Two different valves were placed in the line to reduce the flow rate to within this range, the flow rates recorded for both the rotameter and bucket and stopwatch methods, the results can be seen in Figures 26 and 27.
It was thought that at about the 25 minute mark the pump had reached a steady state and that this would mean that the system would need to run for this period of time before any calibrations or experiments could be run. However experiments will take over an hour to conduct and if there is no data to show that how the pump behaves after this point in time more issues would occur. Therefore a test of the flow rate over 2 hours took place. This test showed similar results as seen in the previous tests, a steady flow rate continues until approximately 60 minutes. After this point there is a steady decline in flow rate. These results show that this configuration for the system will not be suitable as steady flow rates are essential.
The action taken to remedy this problem was installing a bypass line that allows the required flow rates to enter the system, and diverts the rest of the flow in the line back to the reservoir. In doing this the back pressure on the pump is reduced and a drop in flow rate did not occur. The results of installing a bypass can be seen in Figures 29 and 30. This shows that there is a fairly consistent flow rate and it will be acceptable for running the system. The cause for the decrease in flow rates is believed be a pump heating and decreasing in its efficiency and therefore reducing flow rate. As the pump continues to get hotter, the flow rate continues to decrease.
Figure 29: Flow rate of SP stream with a bypass installed.

Figure 30: Flow rate of bypass stream

Inconsistent flow rates through valve at bottom of tank (simulated demand)

It was noticed during an experimental run that was observing the decrease in tank height with time that when steady state (level maintained with respect to time) was approaching the flow rate out of the tank did not remain steady.

The flow rate from the bottom of the tank was tested by bucket and stopwatch method during two emptying cycles to see if the flow rate out at given heights in the tank had changed. Figure 32 shows the results of this test, it can be see that second round of testing flow rates was significantly lower.
Having unpredictable flow rates such is this is not suitable for the experiments that are required to be run for this project. To overcome this issue the needle valve was opened fully and had a flexible tube attached, this tube was compressed by a g-clamp as the mechanism to reduce flow, see Figure 8D. This method produced consistent flow rates as shown in Figure 31.

![Figure 31: Flow of water exiting tank (simulated demand) with new method for controlling flow rate.](image1)

![Figure 32: Change in flow rate of water exiting tank (simulated demand).](image2)