Reducing Nitrate Levels from Drinking Water in WA Aboriginal Homeland Communities: Testing the Viability of Small-Scale Reverse Osmosis

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Abstract

Background: Remote communities usually suffer from poor quality drinking water. One common contaminant in said drinking water that is present in Western Australian remote communities is Nitrates. High Nitrates can have detrimental health effects such as cancer, kidney problems, and Infant methemoglobinemia (Blue Baby Syndrome). The EVOFILTER Reverse Osmosis (RO) filtration system is a possible end of pipe solution to this problem. Untreated water is inputted into the system via a water pump and is forced through a Reverse Osmosis membrane and outputted to 2 output streams: the filter stream which contains fresh treated water that has passed through the membrane, and the waste stream contains water that is heavily laden with contaminants kept out by the pore size of the membrane.

Aim: This research aims to determine the suitability of the EVOFILTER system as a solution to the problem of high nitrate levels present in the drinking water of Remote Communities. This was done through varying the parameters of the water inputted into the system, along with determining the systems effectiveness in removing other contaminants.

Content: Real water samples were obtained from 3 different areas from the Remote Community known as Pandanus Park (Pat's House, Refresh Centre and Office). The Nitrate concentration of the samples were obtained using the Ion Chromatography system. Due to limited supplies of real water samples, synthetic water samples were created using Deionized (DI) water spiked with Nitrates in the form of Sodium Nitrate ($NaNO_3$) to the concentrations found in the real water samples (~60-63 ppm or mg/l). These water samples were then run through the EVOFILTER system to determine the systems effectiveness in removing nitrates from drinking water. Parameters such as temperature and nitrate levels of the input water were varied to determine their effect on the system's ability to filter nitrates, however analysis done on the resultant filtered water (via Ion Chromatography) showed minimal changes to the system's ability to filter out >99% of the nitrates found in the input stream. The system also displayed the ability to filter out Uranium and Arsenic to values of

<1µg/l, however an analysis of the waste stream revealed that the filter had a tendency to retain uranium ions instead of flushing it out in the waste stream. Despite the systems low yield rate of only 25-30%, its high effectiveness, portable design, ability to withstand brownouts with minimal damage, the upcoming improvements planned by the producer EVODROP, along with their humanitarian intent, makes the EVODROP reverse osmosis system a suitable solution to the issue of contaminated drinking water found in remote Western Australian communities.

Declaration

I declare that this thesis is formed from my own research (except where properly cited and acknowledged), with the contents of the main body containing research that has not previously been submitted.

Brandon Lim Zhi Li

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Section 1 – Literature Review

1. Introduction

The dangers of lack of access to uncontaminated water sources for consumption still remains a prevalent issue worldwide. Even in developed countries such as Australia, resources are limited and thus have to be focused on areas with the highest population density in order to maximize the efficiency of resource use. As a result, large cities within Western Australia such as Perth usually have multiple large treatment plants in order to ensure an easy, continuous supple of safe, clean, and fresh drinking water. Consequently, people who live in more remote communities usually lack access to the resources needed in order to treat the groundwater that they rely on as a water source (Harris, 2019). Groundwater drawn from ever diminishing underground water tables through the use of bores, is usually rich in minerals and other contaminants (Evans, 2009). When the concentration of these contaminants is below a certain level such as those stated in the Australian Drinking Water Guidelines or ADWG (NHMRC, NRMMC, 2011), long term consumption has minimal to negligible consequences to the health of the consumer. However, as is the case with multiple remote communities, the groundwater they rely often contain one or more contaminants that exceed the safe limits stated in the ADWG.

One of the main contaminants that plague remote Western Australian communities is nitrates. The ADWG recommends that the safe concentration limits of nitrates present in drinking water to be below 50 mg/l for children and below 100 mg/l for adults. Concentration levels exceeding this amount can have negative consequences on the welfare of the consumer. Such consequences include various forms of cancer in adults (Blaisdell et al., 2019), kidney disease (Rajapakse, 2019), and most worrisome of all infant methemoglobinemia or blue baby syndrome whereby the red blood cells are unable to carry oxygen throughout the body of an infant (Gonzalez-Lopez & Gonzalez-Martinez, 2021). Nitrates have also been shown to mobilize other contaminants such as uranium and lead which have their own negative consequences on the consumer. A report done by the Auditor General of Western Australia (Australian General of Western Australia, 2015), shows that multiple remote communities within Western Australia far exceed the 50 mg/l safe concentration recommended by the ADWG as seen in the figure below:

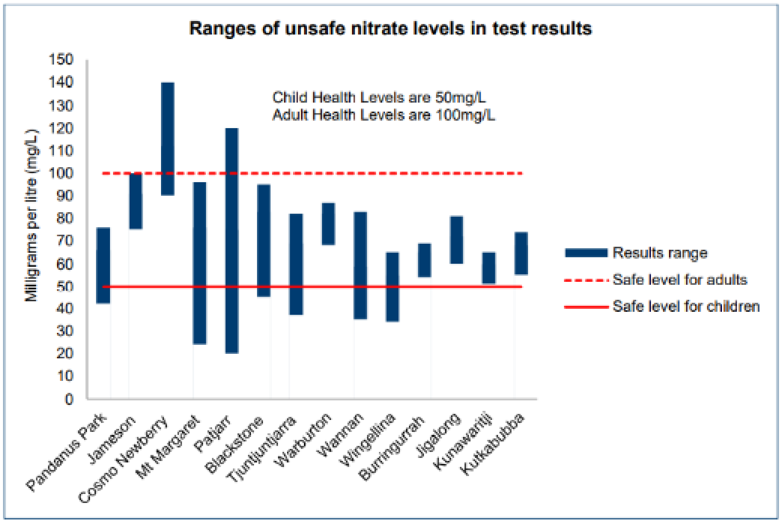

Figure 1: A graph showing the results of an analysis done on the level of nitrates found in drinking water in remote communities within Western Australia (Auditor General of Western Australia, 2015)

As Figure 1 shows, the level of nitrates in these communities exceed the safe 50mg/L limit set in the ADWG for children, affecting the health of the next generation of residents within these remote communities. Some of these communities such as Pandanus Park have already started noticing the problem with their drinking water and have started to actively work towards finding a solution to the issue (Moore & Kurmelovs, 2021).

A possible solution to the problem of contaminated is through the use of a reverse osmosis (RO) membrane filter. This works through using pressure (provided by a pump) to force the water molecules present in the input water through a semi-permeable membrane. Due to the pore size of the membrane, water molecules pass through the membrane, whilst larger molecules such as nitrates are kept on the outside of the membrane. The water kept out by the membrane now laden with a higher concentration of contaminants is washed out of one of the 2 output streams referred to in this report as the waste stream. The filtered water is then pushed out through the second output stream, referred to in this report as the filtered stream. One such filter that contains an RO membrane is the EVOFILTER system developed by the Swiss company EVODROP. The system is relatively compact with dimensions in mm of 110 x 410 x 390 (Width x Height x Depth) and weighing approximately 14 kg, making it a good compact, end of pipe solution to the problem of high nitrate concentration present in the drinking water of remote Western Australian (WA) communities. The system seems to be undamaged by instant and frequent power cuts such as those caused by brown outs that are common in remote communities. Of course, further testing of the system needed to be done in order to determine the systems suitability to be used as a method to filter out nitrates and ensure safe drinking water for all. The main goal of this study is to determine how the situation of high nitrate levels in the drinking water of Pandanus Park can be alleviated in order to mitigate the negative health consequences brought on by high nitrate levels. To do that a few objectives can be examined:

- Determining a suitable method of analysing nitrate concentration in water sample.
- Determining nitrate concentration in water samples.
- Confirming that the EVOFilter by EVODROP is able to filter nitrates from water samples.
- Determination of the yield rate of the filter.
- Determination of how yield changes with operation parameters.
- Determining whether the filter is able to treat higher concentration of nitrates.
- Determining if the filter is suitable for the community.

2. Background

Within Western Australia (WA) there are approximately 17000 people accommodated within 287 communities, of which 155 are considered remote where water services aren't centralized and is essentially self-supplied. (Australian Bureau of Statistics, 2018). Approximately 75% of these communities with a population under 50 rely on groundwater bores to obtain freshwater. (Department of Water 2009). These remote communities tend to suffer from a lack of resources and essential services such as centralized water treatment and power generation, as governments tend to focus resources on high population density areas in order to maximize efficiency of resource use. As a result, they suffer from lack of healthcare, equipment (Australian Institute of Health and Welfare, 2022), frequent brownouts, and poor quality drinking water (Auditor General of Western Australia, 2015, 2021).

3. Groundwater Contaminants

Depending on the area, groundwater could contain many harmful contaminants (Evans 2009) such as:

3.1. Metals

Aluminium (Al), Copper (Cu), Chromium (Cu), Arsenic (AS) etc are often found in groundwater. In some cases where water contains high levels of metals such as Arsenic, chronic exposure through consumption has led to long term health problems such as dermal, cardiovascular, cancer, respiratory disease amongst others (Dipankar Chakraborti, 2017).

3.2. Petroleum Hydrocarbons

BTEX (Benzene, Toluene, Ethylbenzene, Xylene) that composes the volatile C6-C9 hydrocarbons. These commonly are present in groundwater due to leakages from underground storage containers/pipes, spills, improper waste management, and leaching from unlined dumping sites such as landfills (Jo, 2008) They are carcinogenic, toxic at high quantities, teratogenic, and have high motility (Qu et al., 2015).

3.3. Pesticides

Pesticides are generally composed of herbicides and insecticides used for pest and plant control. These compounds contaminate the groundwater via industrial/agriculture runoff and infiltration of the soil. The pesticides that do not degrade will continually accumulate or get mobilized with currently unknown effects on human health (Syafrudin, 2021).

3.4. Nutrients

The nutrients that are most concerning when determining the quality of groundwater include Nitrogen and Phosphorus. While naturally occurring, the result of human development such as farming, and development has led to an artificial increase in the nutrient levels within groundwater. This is true of remote communities that have to rely on methods such as small scale farming as a method of obtaining a steady food source. Fertilizers containing nitrates cause the acceleration of food growth and ensure their health. However, as a result of nutrient increase some remote communities have started to notice adverse effects from their groundwater (Rajapakse, 2019; Thorburn, 2003). The main factor seems to be high nitrate levels. Nitrogen is found naturally in groundwater due to the nitrogen cycle. Sources of Nitrogen (N_2) gets converted to ammonium (NH_4) where via the process of nitrification, it gets converted to nitrates (NO_3) and nitrites (NO_2). However, artificially raised N_2 levels from development and fertilizers means that more nitrates and nitrites are infiltrating into the aquifers than can be removed naturally via denitrification in the nitrogen cycle (Katz, 2020). While the Australian Water Drinking Guide (NHMRC, NRMMC, 2011), claims that water with a level below 50 mg/L and up to 100 mg/L is safe to drink, studies (such as those discussed in the next section. have shown that there are adverse effects to drinking water with high nitrate levels.

4. Dangers of High Nitrate Levels

Some of these adverse effects include:

4.1. Blue baby syndrome

Blue baby syndrome is also known as infant methemoglobinemia. This is where an infants skin turns blue due to lack of oxygen in the blood. This can be caused by the conversion of haemoglobin to methaemoglobin through oxidation caused by nitrates. This inhibits the cell's ability to move oxygen through the blood (Gonzalez-Lopez & Gonzalez-Martinez, 2021). As a result of this possibility, the Australian Drinking Water Guide (ADWG) recommends that infants shouldn't consume water that has >50mg/L of nitrates.

4.2. Cancer

Nitrates have been linked to the causes of multiple forms of cancer including Childhood Brain Tumours (CBT) (Weng et al., 2011), Gastric Cancer (depending on Mg and Ca levels) (Chiu et al., 2012), and Rectal Cancer (depending on Ca levels) (Chang et al., 2010). These papers show that whilst there is a link between cancer development and nitrate level (N-NO_3), it is dependent on and exacerbated by the level of metal minerals in the water. Thus, it is prudent to also determine the level of metals in water.

4.3. Risk of Congenital Anomalies

Studies have linked high nitrate levels with congenital defects and anomalies (Blaisdell et al., 2019; Stayner et al. 2022), suggesting an increased risk in congenital limb deficiencies and a slight risk in congenital heart deficiencies.

4.4. Dangers of Nitrates Discussion

The data (Blaisdell et al., 2019; Chang et al., 2010; Chiu et al., 2012; Gonzalez-Lopez & Gonzalez-Martinez, 2021) shows that while high nitrate levels have an effect on adults, it has a much greater effect on vulnerable groups such as infants, children, and pregnant women. Most of the research done used data from more urban areas around the world. While they demonstrate the possible risk on a worldwide scale, they don't account for Australians who use groundwater bores to obtain water, with most rural data studying the effects of groundwater access through an open well, allowing for easier contamination. A study done in a remote Australian community (Rajapakse, 2019) suggests a link between nitrate mobilizing uranium ions as a cause of chronic kidney disease (CKD). However, whilst it showed that such a link exists, it failed to prove that nitrates were in fact the cause of CKD, as it did not account for the portion of aboriginal patients who suffers from CKD from other reasons. Thus, further research is required into nitrate contamination in remote Australian communities.

5. Possible Communities to Investigate

To conduct said research, a site location must be chosen to do an analysis on. While centralized water treatment plants have rendered freshwater potable within urban areas, there are still reports of high nitrate levels in large swathes of groundwater within Australia. In the north-eastern areas (Thorburn, 2019), the central arid area (Salvestrin & Hagare, 2009), and in the northern goldmines area within Western Australia (Johnson, 1999). A chemical analysis shows that within Western Australia, Nitrate levels can range from <1mg/L in the Paleochannel Tributary to 130mg/L within the Alluvium (Johnson, 1999). There is however a lack of data for central and southern Western Australia. Whilst that might be an indicator that there isn’t a problem with Nitrate levels, a report about essential services (Australian General of Western Australia, 2015) and its follow-up (Australian General of Western Australia, 2021) seems to indicate that the lack of data is due to limited funding and governmental policies which has led to limited attention paid to these areas, especially within the smallest remote communities. As a result of this, there is an undeniable increase in the risk of unmonitored negative health effects from drinking water contaminated with high levels of nitrates. The 2015 report also states that one in five communities within Western Australia failed the safe uranium and nitrate test.

6. Pandanus Park

One of the aforementioned remote communities is Pandanus Park. Whilst according to the 2015 report, it isn't the community with the highest tested levels of nitrates, the level of nitrates detected within the test sample taken from the site showed that it failed the safe limit test within 2013-2014, with levels reaching >70mg/l (Auditor General of Western Australia, 2015). The 2021 follow up report results revealed that the nitrate levels have from their groundwater sources have increased. This community was chosen over others with a higher nitrate level such as Cosmo Newberry (Auditor General of Western Australia, 2015), as it is one of the few that showed an increase in nitrate levels in the 2021 follow up report. Along with that, the community reached out and provided water samples for analysis and testing demonstrating strong community engagement. As such implementation of any conclusions derived in this thesis would be more viable.

Pandanus Park is located approximately 56 kilometres south of derby and is allocated approximately 87.4 hectares of land. As of 2018, the population fluctuates between 60 to 100 people (Department of Planning, 2018). Currently there is one water filter present at the community centre, however due to the distance from the community centre to individual houses, most inhabitants just drink the nitrate laden tap water (Kurmelovs & Moore, 2021). Thus, an end of pipe treatment system is needed to mitigate the health risk to the indigenous inhabitants of Pandanus Park.

7. Analysis Methods

The obtained water samples will be analysed in order to determine the severity of the nitrate contamination to select the most appropriate treatment method. There are multiple methods of analysing nitrate levels within solution (Alahi & Mukhopadhyay, 2018), however they fall mostly in two categories: Direct and Indirect.

7.1. Direct Detection Methods

Direct methods are economical and accurate. However, they are prone to interference from other contaminants that would skew the results. A few direct detection methods are:

7.1.1. Potentiometric Detection

This is where two half-cells which both contain electrodes are submerged in an ion solution. Then the activity between the electrodes is detected. An inert electrolyte is used as a salt bridge between the two half-cells, an example being KCl. Ion Selective Electrodes (ISE) such as ones composing of a doped polypyrrole selective membrane can be used to account for the free-ion concentration of Nitrates in water (Bendikov & Harmon, 2005). The advantage of this method is that it is low cost, portable, has no requirement for pre-treatment and the sample is not consumed in the detection.

7.1.2. Amperometric Detection

An electrochemical method where a sensing electrode is used to detect nitrates in solution. A constant potential (controlled through instrumentation) is applied to the sensing electrode and the current (the resultant of oxidation/reduction) is recorded as a function of time. A small addition of acid copper sulfate is added to the sample and the current is measured using a potential pulse sequence. The current (resultant from the reduction of nitrate on a freshly plated copper surface) can then be plotted as a function of time in order to determine the nitrate concentration in the sample. This works best for a nitrate concentration of 0.1-1mM, and the main advantage is that it tends so ignore most interference (Carpenter & Pletcher, 1995) and is used in High Precision Liquid Chromatography (HPLC), however it may be prone to inaccuracy due to inability to detect free ions.

7.1.3. Voltammetric Detection

An electrochemical detection method composing of 3 electrodes (Reference, working and counter electrodes), which measure the reduction and oxidation process of any molecular species. The working electrode carries out a chemical reaction which changes the potential applied. The reference electrode is used as a baseline to determine the change in potential of the other two electrodes. Some methods that use voltammetric detection to detect the nitrate level in solution involve electrochemically depositing copper and cadmium on a pyrolytic graphite working electrode (Bodini & Sawyer, 1977), a spinning cadmium disc used as an electrode (Davenport & Johnson, 1973), or silver electrodes (Krista et al., 2000). Of these 3 methods, the one developed by Krista et al. consisting of electrodes prepared using silver, resin and graphite powder is the most updated and accurate with good reproducibility. However, it requires a separate computer-controlled system to run.

7.1.4. Biosensors

A slightly unconventional method of nitrate detection in water. Biological materials such as an enzyme are used in concurrence with a specialized detection system and signal conditioning circuit in order to determine the concentration of the targeted ions within the sample. An experiment involving a fast, stable and conductometric enzyme biosensor was developed and used in conjunction with electrodes mixed with nitrate reductase in order to detect nitrate levels within a water sample (Xuejiang et al., 2006). The resulting method resulted in fast data analysis, high calibration, and low detection limit. The major disadvantage is that the enzymes have a shelf life of around 2 weeks.

7.2. Indirect Detection Methods

Indirect methods usually involve complicated machinery, chemicals, and training all adding up to high costs. However, indirect methods provide the most accurate results (Alahi & Mukhopadhyay, 2018) and thus have been chosen to most accurate determining the effectiveness of the treatment method. The two main methods considered are:

7.2.1. High Performance Liquid Chromatography (HPLC)

HPLC is a form of column chromatography. The sample to be analysed is pumped in a solvent solution at high pressure (mobile phase) through a column containing chromatographic packing material (stationary phase). The sample is moved using a carrier gas stream such as nitrogen or helium. The process then separates the individual compounds present in the solvent sample which then can be analysed to determine the concentration of individual compounds present. Analysis can be done using a diode array detector (DAD) (Liu et al., 2013), or photochemical reaction and chemiluminescence detection (Kodamatani, 2009). The main disadvantage of HPLC over Ion Chromatography (IC) is that it mainly detects compounds and has difficulty accounting for the free ions within the sample and (in terms of this study) that it requires additional reagents that must be procured.

7.2.2. Ion Chromatography (IC)

A form of column chromatography, IC works by first separating ionic species within the sample thorough its interaction with a resin. The sample is then forced through a column under high pressure, where the ions are absorbed by the components of the column. It then washed out using an ion extraction liquid known as an eluent. The retention time of different species is then analysed to determine the ionic concentrations of the sample. IC systems have more accuracy than direct measurement systems and is able to account for interference from other contaminants (Alahi & Mukhopadhyay, 2018). The main advantage of the system over HPLC is its ability to account for nitrogen content within water not in compound form such as NO_3^-, NO_2^- and NH_4^+ (Michalski & Kurzyca, 2005; Murray et al., 2020). Another reason this method was chosen as there is a functional IC system within Murdoch that can be used to detect nitrates in samples.

8. Possible Treatment Methods

8.1. Criteria

Once the nitrate detection has been determined, a treatment option must be chosen. Based on the social-economical situation of Pandanus Park, the treatment method should meet the following criteria:

- Low Cost – The Auditor Generals 2015 report suggests that there is not a lot of funding for the improvement of infrastructure for remote communities, thus when selecting a treatment method, the cost of a unit must be considered.
- End of Pipe system – It has been stated that most of the community prefers to drink the nitrate laden tap water over filtered water as the trip to reach the filter is too far. Based on this behaviour, it is implied that an end of pipe system installed within their homes is a preferred option (Kurmelovs & Moore, 2021).
- Low Maintenance – The system should be robust and low maintenance in order to run and be robust enough to require little attention from the operator. Skilled operators should not be needed to run the treatment system.

Based on the criteria, and the knowledge that most conventional treatment systems are unable to deal with Nitrates in solution, there are 3 main treatment options that may prove the most effective: Ion Exchange, Electrodialysis and Nanofiltration.

8.2. Ion Exchange

Ion exchange (IE) is a chemical process whereby water is passed through the exchange material (also known as the resin). Within the resin, the nitrate ions are exchanged with their equivalent number of ions present in the exchange materials (usually chloride ions). The ion exchange resin for the removal of nitrates is usually anionic and is weakly or strongly basic. The main advantages are that the process is not affected by temperatures beyond operation range, is easy to automate and it offers process control (Canter, 1997). However this fails to account for the main disadvantages of the ion exchange process; the need for regeneration of the resin requires either skilled staff or continuous maintenance costs. The by-product of the ion exchange process also produces a highly concentrated nitrate stream. This stream will need to be carefully disposed of in order to not further contaminate the surroundings (Salvestrin & Hagare 2009). Thus, this method fails to meet both the low cost and low maintenance criteria requirements. Of course, research has been done in order to minimize the production of the reject and to recycle it back (Klas et al., 2015), it is not really viable for residents of a remote community and would only drive up costs more.

8.3. Electrodialysis

Electrodialysis (ED) is a membrane process whereby charged membranes and electric potential differences are used in order to separate charged ionic species from water and other uncharged species. ED has previously been proven to be effective in removing nitrate from groundwater before (Elmidaoui et al., 2001; Aliaskari & Schäfer, 2021). The studies show that the system can reduce the concentration of nitrates in water from 78 mg/L to <20 mg/L after 10 min (Elmidaoui et al., 2001). The advantages are that the system is relatively easy to run and has lower capital costs. However, one must also account for the higher than average operation costs from the electrical current needed (Aliaskari & Schäfer, 2021) which may be hard to provide in remote communities. Research has been done to try optimizing the ED process by changing parameters to reduce the impact of the reject stream and optimize energy uses (Elmidaoui et al., 2002), however, to maintain these operation conditions and the skilled labour needed is greater than what is optimal for remote communities.

8.4. Nanofiltration

Nanofiltration (NF) is a physical membrane process of separating contaminants from water. Sharing many similarities to the reverse osmosis (RO) systems, they both push the feed water through a membrane filter under high pressures. The pore size of the membrane prevents contaminants from passing through and is instead washed away into the reject stream. The purified water is then let out through the output stream. Nanofiltration and reverse osmosis have been proven to be capable of filtering nitrates (Bohdziewicz et al., 1999; Epsztein et al., 2015; Labarca & Bórquez, 2020). The main difference between an RO and NF system is the type of membranes. NF membranes are less selective and allow some other species through which means lower operational costs as pressures do not have to be as high and the membranes last longer due to less strain. They are also capable of variable retention of anions (Bohdziewicz et al., 1999). There are a few disadvantages to a NF system. They produce a waste stream that must be disposed of carefully as they have a higher concentration of nitrates, they have quite high capital costs which does not meet the low costs requirement and the system requires a pre-treatment process in order to extend the life of the membrane (Labarca & Bórquez, 2020). However, the main advantage is that they can be made small and less power intensive in order to be used as an end of pipe, in home system that can be attached to the tap and thus meeting the second requirement. An example of such a system is the EVOFilter system developed by EVODROP. The system claims to be able to filter nitrates as the pore size of the membrane is around 0.0009 micrometres compared to the 0.001 micrometre of nitrate particles (EVODROP, 2021). The manufacturer has stated that they would be willing to sell the system to the communities at cost price (thus meeting the low cost requirement of the criteria) as they are more inclined towards humanitarian goals than profit and the pre-treatment systems are contained within the unit and can process 10 KL of water before needing replacement (thus fulfilling the low maintenance criteria). Further experimentation will be required to determine the suitability of the system to the remote community such as operation conditions (Labarca & Bórquez demonstrated that operation conditions can greatly affect the output of NF systems) and system requirements.

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Section 2 – Research Manuscript

1. Materials and Methods

1.1. Obtaining Water Samples

Water samples were obtained from the medium sized remote community known as Pandanus Park located south of Derby within the Kimberly region of Western Australia. The community provided approximately 4.4 Litres each of 3 real water samples from 3 different areas within Pandanus Park named: Pat's House, Refresh Centre, and Office for a total of 13.2 litters of Real Water Sample. The samples were stored in multiple reused 600mL water bottles for transport. The cap of the bottled samples from Pat's House were taped up to seal the bottles and limit water loss due to evaporation, whilst the samples from Refresh Centre and Office weren't (See Appendix Figure A 2). Once received, the real water samples were immediately transported and stored in a refrigerator kept at 5°C in order to slow water loss due to evaporation (See Appendix Figure A 5).

1.2. Analysis of Nitrate Concentration

With the water samples obtained, the next step was to determine the optimal method to analyse the water samples and obtain an accurate reading of the nitrate concentration. The 3 main methods considered were:

1.2.1 Vernier^{TM} Nitrate Probe

A Vernier^{TM} Nitrate Ion Selective Electrode (ISE) was the first option considered. The main consideration for this method was its ability to quickly obtain the nitrate concentration of an aqueous solution in real time. However, upon testing by inserting the probe into the waste stream, before cleaning (with Deionised Water) and inserting into the filtered stream, it was discovered that whilst the probe was able to easily obtain the nitrate concentration of the waste stream of 83mg/L, it had trouble detecting lower concentrations such as the concentration of the filter stream which was less than 1mg/:. Thus, this method was not chosen as the primary method of analysis but was kept in mind for when quick rough readings of nitrate concentrations estimated to be >1 ppm was required.

1.2.2 High – Performance Liquid Chromatography (HPLC)

HPLC is a form of column chromatography. This method was considered for its high degree of accuracy and precision along. However, it was discarded as an option for 2 main reasons. The first was that it required additional expensive chemical reagents in order to run and was deemed ineligible due to budgetary limitations. The second and more important reason it was not chosen as the primary method of analysis was that the HPLC system often had trouble detecting free nitrate ions.

1.2.3 Ion Chromatography (IC)

IC is another form of column separation and is the primary method of detecting nitrate concentration in water chosen for this research. The detection method was built off of the following paper (Dionex, 1991). This method was chosen for several reasons such as high accuracy, precision, the ability to take interfering ions into account, the ability to detect free floating nitrate ions and the fact that it was available within Murdoch University for training and use. The basic premise behind the operation of the IC is that it first separated the ionic species within the water sample thorough its interaction with a resin. The sample is then forced through a column under high pressure, where the ions are absorbed by the components of the column. It is then washed out using an ion extraction liquid known as an eluent. The retention time of different species is then analysed to determine the ionic concentrations of the sample. Based on the retention time and the current reading, it is possible to create a calibration curve created using a solution of nitrate with known concentration (as a stock standard). By comparing the readings of unknown samples against that of the calibration curve created with a stock standard, it is possible to determine the unknown concentration of nitrate in a water sample.

1.2.3.1 Creating Nitrate Standard for the IC

For the purpose of the experiments analysed under this report, a stock nitrate standard was created as there was no lab grade standard available at the time. To achieve this 0.0686g of analytical grade sodium nitrate ($NaNO_3$) [99.0% Purity] was weighed on a weighing scale then transferred into a freshly opened plastic container (to minimize other contaminants). 50mL of Type 1 ultrapure water was obtained from Ibis Technology^{TM} Simplicity UV filter at 18.2 mΩ (See Appendix Figure A 4). The water was then poured into the plastic container containing the sodium nitrate, capped, then vigorously shaken. The resultant product was a 50mL of a stock nitrate standard of 100ppm. Then a series of simple dilutions were done to create an analytical range for the IC to create a calibration curve. The following dilution formula

$$C_1V_1 = C_2V_2$$

Equation 1: The dilution formula

was used to determine the amount of the stock solution needed to create the series of nitrate standards used in the calibration curve. C_1 represents the initial 100ppm concentration of the stock nitrate standard solution, V_1 represents the volume of said stock nitrate standard needed to reach the final desired concentration, C_2 represents the final desired nitrate concentration and V_2 represents the final volume of the desired nitrate standard. For the sake of simplicity, V_2 was set to 50mL. The following table demonstrates the amount of the stock solution used to create the series of nitrate standards:

Table 1: Table of data demonstrating the concentration and volume of stock nitrate solution used to create the series of nitrate standards used for the calibration curve for IC analysis

Preparation of Nitrate Standard for IC				
Desired NO_3 Conc. (ppm)	**C_1 (ppm) [Initial]**	**V_1 (mL)[Initial]**	**C_2 (ppm) [Final]**	**V2 (mL)[Final]**
5	100	2.5	5	50
10	100	5	10	50
15	100	7.5	15	50
20	100	10	20	50
25	100	12.5	25	50
30	100	7.5	30	25

The following nitrate standards were then filtered through a PES 0.22µm filter (See Appendix Figure A 3) to remove large debris into the provided glass vial with injection tops and placed into the autosampler portion of the IC. The samples were then run through and labelled in the accompanying analytical software of the IC known as Chromeleon^{TM}, set as standards and then used to create a calibration curve (See Appendix Figure B 1).

1.2.3.2 IC Analysis Method

The IC was set up with an AS19 Analytical column (20 x 250mm) with an AS19 guards to prevent the column from flooding. Due to the relatively small size of the column, it was important to ensure that any samples placed into the IC had to have their nitrate concentration estimated, then diluted down to below 30ppm using Type 1 ultrapure water. The Eluent used was hydroxide in the form of water run through a deionised filter, before running it through the from Ibis Technology^{TM} Simplicity UV filter at 18.2 mΩ. The following solution was then run through the Sonicator for 15 minutes before being used as an eluent with an approximate concentration of 30mM in the IC. The cartridge type chosen for this experiment was EGC KOH. In the accompanying Chromeleon^{TM} software, the following experimental method was chosen and created to analyse water samples for their nitrate concentrations. The column flow rate was set to 0.25mL/min and the run type changed into an Isocratic type with a runtime of 7 minutes. This runtime was chosen off of the (Dionex, 1991) paper which showed that the peak for nitrates appeared before 7 minutes in the readings, and thus was chosen to shorten the analytical time and boost efficiency. The injection volume was set to 5µL, and each sample was then set to be run twice to reduce system error through repetition. The current was set to a constant 19mA. The IC's ability to heat up the samples no longer functioned properly, and thus to work around it, the column temperature was set to 30°C and the compartment temperature was left to its default of 21°C (See Appendix Figure B 2).

1.2.3.3 Sample Preparation Method

The following method is the general steps taken to prepare water samples produced during experiments for nitrate concentration analysis in the IC. First all the water samples were stored in an unopened fresh 50mL plastic container (See Appendix Figure A 1) to prevent contamination from previous use. Then their nitrate concentrations were estimated based on the research done. Using Equation 1: The dilution formula, a certain amount was extracted from the water samples using an auto-pipette and transferred into a second unopened 50mL plastic container. Type 1 ultrapure water was then used to dilute the sample, aiming for a concentration of 20ppm. The diluted sample was vigorously shaken to mix. A new disposable syringe was then used to extract approximately 3mL of the diluted water sample, before it was filtered through a PES 0.22µm filter into a an autosampler glass vial with an injection top. The vial was then inserted into the autosampler tray as shown in the Figure below:

Figure 2: A picture of an IC's autosampler tray with samples inserted

Then based off of the position of the sample to be analysed, determined by the letter and number seen on the sides of the autosampler tray in Figure 2, the sample was then inserted into the Chromeleon^{TM} software, labelled as an unknown, and run through the IC Analysis Method. The resultant current peak was then compared to the calibration curve and the nitrate concentration present in the sample determined. Equation 1 was used as a reverse dilution formula to calculate the exact nitrate concentration of the sample

1.3. Testing the effectiveness of the EVOFILTER System

The first set of experiments to be done was to determine the baseline effectiveness of the system by figuring out some of the input and output variables and constants. The following are the series of sub experiments done to figure out these parameters.

1.3.1 Input Flow Rate

To determine the water required for experiments, it was crucial to determine the input flow rate of the EVOFILTER system. The EVOFILTER system has an internal pump to draw water through the intake tube to act an input, however it does recommend an input water pressure of 1.9 to 6 bar. The input flow rate was determined through the use of a 2L beaker and a stopwatch. The beaker was filled to the 2L mark with Deionised (DI) water and the intake tube was inserted into the beaker. The system was started up and when the systems pump started up, so did a stopwatch. Once the water volume had reduced by 500mL, the stopwatch and the system were stopped simultaneously. Then the volume reduced was divided by the time to determine the input flow rate in mL/s. This was repeated 5 times (stopping to refill the water in the beaker) to reduce error and determine an average input flow rate.

1.3.2 Recovery Yield

For various parts of the experiment, the recovery yield of the system needed to be determined. For this, it was assumed that the input volume of water = volume of water out of the waste stream + volume of water out of the filtered stream. In order to determine the recovery rate, a 2L beaker was filled with DI water and the intake tube was inserted. Then 2, 1L beakers were placed at the waste stream tube and the filtered stream tube to collect the output water. The system was started then stopped once approximately 500mL of the water at the intake tube had been drawn into the system. Then the following equation was used:

$$Recovery\ yield\ (\%) = \frac{\text{Volume of Filtered Stream}}{(\text{Volume of Filtered Stream} + \text{Volume of Waste Stream})} \times 100\%$$

Equation 2: Equation to determine the recovery yield of the system

It was possible to determine what the yield of the filtered stream of the system was. This was repeated 5 times (stopping to refill the water in the beaker) to reduce error and determine an average recovery yield.

1.4. Simulated Viability Test

When comparing the amount of water needed for all tests calculated based on input flow rate and that of available real water samples sent from Pandanus Park, it was apparent very early on that there was not enough water sample to run all the planned experiments, even discounting repeats to reduce error and assuming perfect runs. Thus, a solution was devised to solve the issue of insufficient water samples. Due to lack of time and budget, it was considered quite impractical to obtain and transport large quantities of real water sample.

Thus, drawing inspiration from the creation of nitrate standards for the IC analysis method, simulated water samples were created by spiking DI water with sodium nitrate. To ensure that the simulated water samples were a viable replacement for the real water samples in testing the system’s ability to remove nitrates, the following steps were taken. Firstly, 4L of the real water sample labelled as Office was run through the system. A sample of the Input and both output streams were collected in unopened 50mL plastic centrifuge tubes. Then the concentration of the input stream was determined via the method described in 1.2.3.3 Sample Preparation Method. 1L of 1000ppm simulated water sample was created by mixing 1.371g of sodium nitrate with 1L of DI water. Then by using Equation 1: The dilution formula, the simulated water was diluted down 5L of simulated water sample with the nitrate concentration to match that of the real water labelled as Office. This simulated sample was then mixed vigorously before running it through the EVOFILTER system. The resultant output streams of simulated water samples were collected in new 50mL plastic centrifuge tubes then run through the analysis method. This was repeated once again to ensure that the first run-through was not an outlier. The nitrate concentration of the input simulated water sample, along with the resultant output nitrate concentrations were then compared to those of the real water sample labelled as Office to determine if simulated water created by spiking DI water with sodium nitrate was an acceptable substitute.

1.5. System Equilibrium Time Period

After running the EVOFILTER system a few times with the simulated water samples, it was noticed that at times, when switching from one concentration to another, the nitrate concentration found within the waste stream was lower than that found in the input stream. This should not be possible as the waste stream not only contains the nitrates of the input stream, but also that of the quantity of water filtered out in the filtered stream, resulting in a higher nitrate concentration than that of the input stream. After some deliberation, it was theorized that it could be because the system hadn’t fully flushed out the water from the previous experiment/cleaning and thus had not reached equilibrium. To determine how much time and thus how much water was required to fully flush out the system and obtain the most optimal water samples, the system equilibrium time period experiment was devised.

Firstly, to achieve faster real time analysis of the nitrate level within the water sample, a Vernier^{TM} nitrate probe was used in place of the usual method of IC analysis. First the probe was washed with DI water and blotted dry with paper towels. Then it was dipped into the provided 1ppm Nitrate Standard and calibrated using the accompanying program LabQuest Mini^{TM} to 1ppm. The Probe was then washed again with DI water and blotted dry with paper towels, before being inserted into the provided 100ppm nitrate standard and calibrated.

Next 1L DI water was added to 1.371g of sodium nitrate to create 1L of 1000ppm simulated nitrate water sample. 500L of this stock sample was poured into a large new plastic container and 4.5L of DI water was added. This diluted simulated nitrate water sample was vigorously shaken to mix well and form 5L of 100ppm simulated nitrate water sample. The intake tube of the EVOFILTER system was inserted into the container and the system started. Every 20 seconds the system was shut off. The Vernier^{TM} Nitrate Probe was then used to determine the nitrate concentration of the input stream, washed with DI water, blotted dry with paper towels, then used to determine the nitrate concentration of the waste stream. The system was then turned on for another 20 seconds before being turned off and the concentration of the waste stream determined using the nitrate probe. This was repeated 5 more times for a total of 140 seconds, with the system being shut off every 20 seconds, a sample of the waste stream collected and then the nitrate concentration of said waste stream determined using the nitrate probe. The whole point of this was to determine in which time period the nitrate concentration of the waste stream exceeded that of the input stream, and at which time period the nitrate concentration of the waste stream stopped increasing. This would indicate the optimal time period to collect samples from the experiment. The minimum amount of water needed for each experiment to ensure a reliable result could then be determined using the following formula:

$$\text{Water Required} = \text{Input Flow Rate} \times \text{Time Period}$$

Equation 3: Formula used to determine the minimum volumetric input water requirements for each run of experiments

1.6. Effect of Temperature Variation on System Operation

Once the initial experiments were done and their problems addressed, the next step was to vary the parameters of the intake water being inputted into the system. The first parameter to be tested was the temperature of the input water. First 1L of 1000ppm nitrate simulated water sample was created by mixing 1.371g of sodium nitrate with 1L of DI water. After that the solution was diluted down to 15L of simulated water sample with a concentration of 65.8ppm (obtained through Equation 1 and later confirmed by IC analysis). This was done by pouring 987mL of the stock solution (measured with 100mL measuring cylinders) into a large plastic container where 14.013 L of DI water was then added. The DI water was added 1L at a time (with the last 13mL added) and the container was vigorously shaken to ensure even mixing and distribution of nitrate in the large sample of water.

The experiment was over a range of 3 temperatures. First 4L of the simulated water was poured into 2, 2L beakers and the temperature was monitored through the use of a digital thermometer. The temperature of the simulated water sample at room temperature that day was 17.8°C. The intake tube was then placed into the first 2L beaker and the system started. The full 2L was inputted into the system before it was shut off. The intake tube was then moved to the second 2L container and 1.5L of the simulated water sample was inputted into the system before sample collection began. Once it was noticed that the water level in the second beaker had dropped below 500mL, sample of the waste stream and filtered stream was taken in new 50mL plastic containers and the system turned off. 3.5L of water was allowed to run through the system first to ensure that all previous experiments had been washed out.

The 2, 2L beakers were refilled with 65.8ppm nitrate containing simulated water sample They were then placed into a water bath set at 25°C and left for 20 minutes for the simulated water sample to reach the desired temperature. Once this was confirmed the intake tube was then placed into the first 2L beaker and the system started. The full 2L was inputted into the system before it was shut off. The intake tube was then moved to the second 2L container and 1.5L of the simulated water sample was inputted into the system before sample collection began. Once it was noticed that the water level in the second beaker had dropped below 500mL, the samples of the waste stream and filtered stream were taken in new 50mL plastic containers and the system was turned off. This process was then repeated again but with the temperature of the water bath increased to 30°C. All the samples that were taken were analysed using the method described in 1.2.3.3 Sample Preparation Method.

1.7. Effect of Nitrate Concentration Variation on System Operation

The second parameter to be varied is the nitrate concentration in the input water. With decreasing water tables due to climate change and a constant nitrate source contaminating the groundwater, the fact is that the nitrate concentration in the drinking water in remote communities will increase over time as the contamination worsens at the source with less fresh water from the water tables to dilute the nitrate concentration. As a result, a test was performed on the EVOFILTER to determine if an increase in nitrate concentration will largely affect the quality of the water coming out of the filtered stream. This was done by first creating 2L of 1000ppm nitrate simulated water sample by mixing 2.742g of sodium nitrate with 2L of DI water. This stock sample was then diluted down to 4L each of the following concentrations: 76.67ppm, 104.16ppm, 243ppm. The following table shows the amount of the stock solution (calculated using Equation 1: The dilution formula) used to create the simulated water samples at the desired concentrations:

Table 2: Table of Dilution Calculations used to create simulated water samples for Nitrate Concentration Variation Experiment

C1 (Concentration of Stock) [ppm]	1000	1000	1000
V1 (Volume of Stock Used) [mL]	306.68	416.64	972
C2 (Desired Concentration) [ppm]	76.67	104.16	243
V2 (Desired Volume) [mL]	4000	4000	4000

These simulated water samples were then vigorously agitated in order to ensure thorough mixing before being decanted into 2, 2L Beakers for a total of 4L of each concentration of simulated water sample. Starting with the lowest nitrate concentration simulated water sample at 76.67ppm, the intake tube was placed into the first 2L beaker and the system started. The full 2L was inputted into the system before it was shut off. The intake tube was then moved to the second 2L container and 1.5L of the simulated water sample was inputted into the system before sample collection began. Once it was noticed that the water level in the second beaker had dropped below 500mL, sample of the waste stream and filtered stream was taken in new 50mL plastic containers and the system turned off. 3.5L of water was allowed to run through the system first to ensure that all previous experiments had been washed out. This was then repeated for the simulated sample containing 104.16ppm of nitrates, then again for the simulated water sample containing

243ppm of nitrates. All the samples that were taken were analysed using the method described in 1.2.3.3 Sample Preparation Method.

1.8. Concentration Change of Uranium and Arsenic

Beside the main contamination of nitrates, it was also important to observe the systems effectiveness on other contaminants that plague the drinking waters of remote WA communities. To do this, samples were sent off to the Marine and Freshwater Research Laboratory (MAFRL) for analysis. Due to budgetary reasons, only two contaminants could be examined. Arsenic and Uranium were the two contaminants that were chosen for analysis. To obtain the water sample, 4L from the refresh centre and Pat's house real water sample sources were run through the EVOFILTER system, with the Office water sample gathered from the Simulated Viability test. Then 10 mL of the input, waste stream, and filtered stream samples were collected and placed in separate plastic bottles provided by MAFRL. The bottles were then labelled with the codes listed in the table below for ease of notation:

Table 3: The coded names of water samples sent to MAFRL for Uranium and Arsenic Testing

Code	Description
OFF-1	Office Input
OFF-2	Office Waste
OFF-3	Office Filtered
RFC-1	Refresh Centre Input
RFC-2	Refresh Centre Waste
RFC-3	Refresh Centre Filtered
PAT-1	Pats House Input
PAT-2	Pats House Waste
PAT-3	Pats House Filtered

The samples were then sent off to MAFRL for testing and the Arsenic and Uranium concentrations were determined using Mass Spectrometry. The exact method of handling the samples and processing it through the Mass Spectrometry was not disclosed and thus has not been included into this report. (See Appendix Figure C 1 for full report)

2. Results

2.1. Results for Testing the Effectiveness of the EVOFILTER System

2.1.1 Input Flow Rate Results

The following table contains the results of the experimental procedure described in 1.3 Testing the effectiveness of the EVOFILTER System. This rate was from obtained through the input source of DI water at room temperature on that day which was measured to be 21°C. The volume of water inputted into the system was rounded and taken as 500mL for consistency. The resultant averaged input flow rate of 58.92 (ml/s) was then considered a constant and used in all following experiments.

Table 4: Data used to determine the input flow rate of the EVOFILTER system

Input Flow Rate		
Volume (mL)	**Time (s)**	**Rate (mL/s)**
500	8.58	58.28
	8.02	62.34
	8.75	57.14
	8.63	57.94
	8.49	58.89
	Average	58.92

2.1.2 Recovery Yield Results

The following table contains the results of the experimental procedure described in 1.3.2 Recovery Yield. This rate was from obtained through the input source of DI water at room temperature that day which was measured to be 21°C. The target volume of the water inputted into the system for each reading was 500mL.

Table 5: Data used to determine the Recovery Yield of the EVOFILTER system

Recovery Yield			
Waste (mL)	**Filter (mL)**	**Total (mL)**	**Recovery (%)**
368	126	494	25.51
374	127	501	25.35
345	120	465	25.81
362	124	486	25.51
371	128	499	25.65
		Average	25.57

Table 5 it can be seen that the averaged recovery rate is considered quite low at 25.57%, meaning that of the 100% intake water inputted into the system, only 25.57% gets filtered out as drinkable fresh drinking water product, whilst 74.43% gets washed out as waste water with higher concentration of nitrates which has to be disposed of in a manner that will not worsen the contamination of the groundwater source.

2.1.3 Initial Concentration of Real Water Samples Results

Small amounts of samples taken from 3 real water samples were analysed in the IC and their nitrate concentration were determined. The following table shows the nitrate concentration of the 3 real water samples obtained from Pandanus Park.

Table 6: Initial Nitrate Concentrations of Real Water Samples from Pandanus Park

Initial Concentration of Real Water Sample		
Location	**Date Collected**	**Conc. (ppm)**
Pats House	23/03/2022	60.04
Refresh Centre	23/03/2022	62.61
Office	23/03/2022	63.41

This data was then used as a general guideline for what nitrate concentrations to aim for when creating simulated water samples with sodium nitrate and DI water for the use of substituting real water samples needed in experiments.

2.2. Simulated Viability Test Results

To combat the issue brought about by lack of real water, simulated water samples were created with the procedures described in 2.4. Simulated Viability Test. The resultant data showed a difference of <1% in the filters effectiveness in removing nitrates as the table below shows:

Table 7: Table of data obtained through the simulated viability test

Sample	Initial Concentration (ppm)	Final Concentration (ppm) [Filtered Stream]	Final Concentration (ppm) [Waste Stream]	Concentration Difference (ppm) [Filtered Stream]	Concentration Difference (ppm) [Waste Stream]	Percentage Removed (%)
Real	63.41	0.1279	78.8	63.2821	15.39	99.798
Simulated 1	65.8	0.0833	102.3	65.7167	36.5	99.873
Simulated 2	65.94	0.0798	98.7	65.8602	32.76	99.879

It should be noted that the concentration figures displayed in Table 7 is an average of the 2 readings done by the IC as described in 1.2.3.2 IC Analysis Method. It was also prudent to check if the simulated water sample would affect the recovery yield of the filter and thus the experimental procedure described in 2.3.2. Recovery Yield was carried out to give the following data:

Sample	Initial Concentration (ppm)	Final Concentration (ppm) [Filtered Stream]	Final Concentration (ppm) [Waste Stream]	Concentration Difference (ppm) [Filtered Stream]	Concentration Difference (ppm) [Waste Stream]	Percentage Removed (%)
Real	63.41	0.1279	78.8	63.2821	15.39	99.798
Simulated 1	65.8	0.0833	102.3	65.7167	36.5	99.873
Simulated 2	65.94	0.0798	98.7	65.8602	32.76	99.879

Table 8: Raw data for obtaining the recovery yield of simulated water

Sample	Waste Trial 1 (ml)	Waste Trial 2 (ml)	Filter Trial 1 (ml)	Filter Trial 2 (ml)
Real	47.73	48.61	16.43	16.27
Simulated 1	47.80	48.44	16.38	16.42
Simulated 2	48.18	48.48	16.13	16.43

Which was then averaged, and the Recovery yield calculated using Equation 2 producing the following table:

Table 9: Recovery yield of Simulated Vs. Real Water Sample

Sample	Average Waste (ml)	Average Filter(ml)	Recovery Yield (%)
Real	48.17	16.35	25.34
Simulated 1	48.12	16.40	25.42
Simulated 2	48.33	16.28	25.20

This data shows that whether in terms of recovery yield of change in nitrate concentration, the simulated water produced using sodium nitrate and DI water is a perfectly viable substitute for the real water sample. Simulated samples were thus used as a substitute for real water sample from Pandanus park in the following study on the effects of temperature and nitrate concentration on the EVOFILTER system operation.

2.3. System Equilibrium Time Period Results

The following table contains the results obtained from determining the best time period to collect water samples for testing and then used to determine the minimum requirement for volume of water needed for each experiment:

Table 10: Data showing the nitrate concentration increase in the waste stream over time

Time (sec)	Input Nitrate Concentration (ppm)	Waste Nitrate Concentration (ppm)
20	92.3	89.4
40		123
60		131.5
80		131.2
100		131.4
120		131.5
140		131.3

As the data in Table 1 shows the nitrate concentration in the waste stream stops increasing in the time period between 40-60 seconds, and after 60 seconds seems to have relatively stabilized at ~131ppm. Thus, a time period of 60 was determined as the minimum time required for the system to reach equilibrium. Then taking into account the average input flow rate of the EVOFILTER system determined in 2.1.1 Input Flow Rate Results, the minimum water required for the system to reach equilibrium can be calculated using the following formula:

$$Minimum\ Water\ Required = Time\ Required\ to\ reach\ equilibrium \times Input\ Flow\ Rate$$

$$= 60\ seconds\ \times \frac{58.92ml}{second} = 3535.2ml \times \frac{1L}{1000ml} = 3.535.2L \approx 3.5L$$

Equation 4: Formula used to determine the minimum water required for system to reach equilibrium

As can be seen from Equation 4, 3.5L is required to fully flush the system, and thus all future experiments needed a minimum of 4L/run to allow for the system to flush and then a good amount for sample collection.

2.4. Effect of Temperature on EVOFILTER System Operation

As the temperature increased, the water became ‘softer’ and had less time to pass through the membrane as a result of this the concentration of nitrates in the filtered rate increased whilst the concentration of nitrate in the waste stream decreased as can be seen in the data below:

Table 11: Data from Temperature Variation Experiment

Temperature (°C)	Initial Concentration (ppm) [Feed]	Final Concentration (ppm) [Filtered Stream]	Concentration Difference (ppm) [between Filtered Stream and Feed]	Final Concentration (ppm) [Waste Stream]	Concentration Difference (ppm) [between Waste Stream and Feed]	Percentage Reduction (%)
17.8	65.8	0.08	65.72	101.02	35.22	99.87
25	65.8	0.10	65.70	98.74	32.94	99.85
30	65.8	0.12	65.68	97.13	31.33	99.82

There is a clear decrease in the percentage reduction of nitrates in the filtered stream along with a decrease in the concentration of nitrates found in the waste stream. From this the rate of decrease can be seen in the following 2 figures:

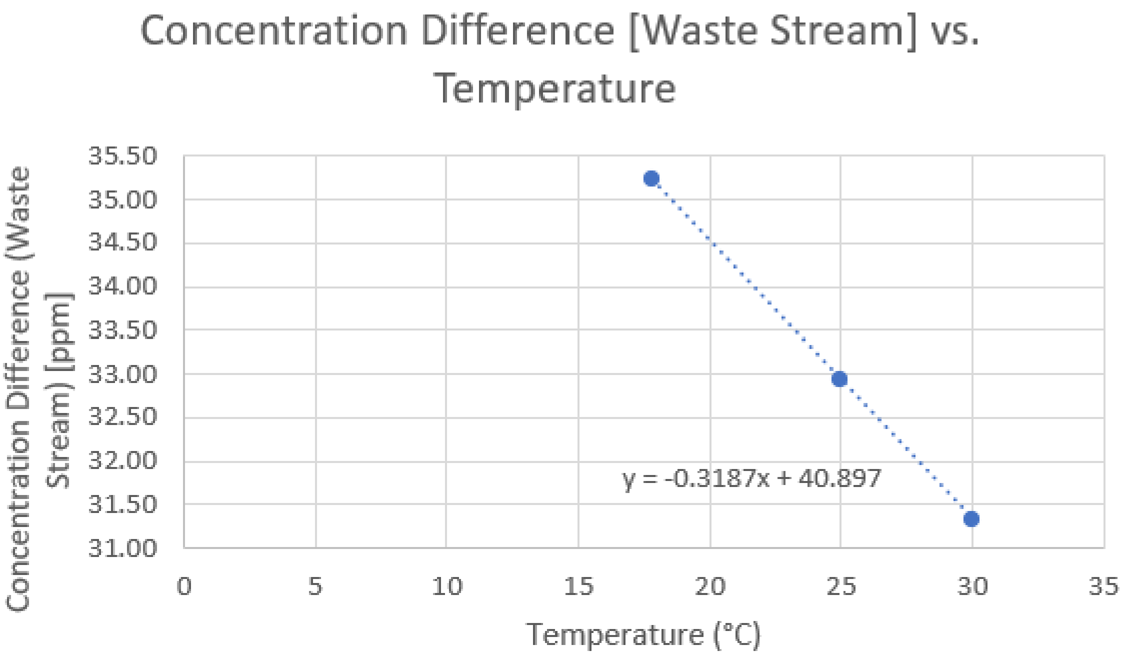


Figure 3: Graph showing the decrease in nitrate concentration found in waste stream as a function of temperature

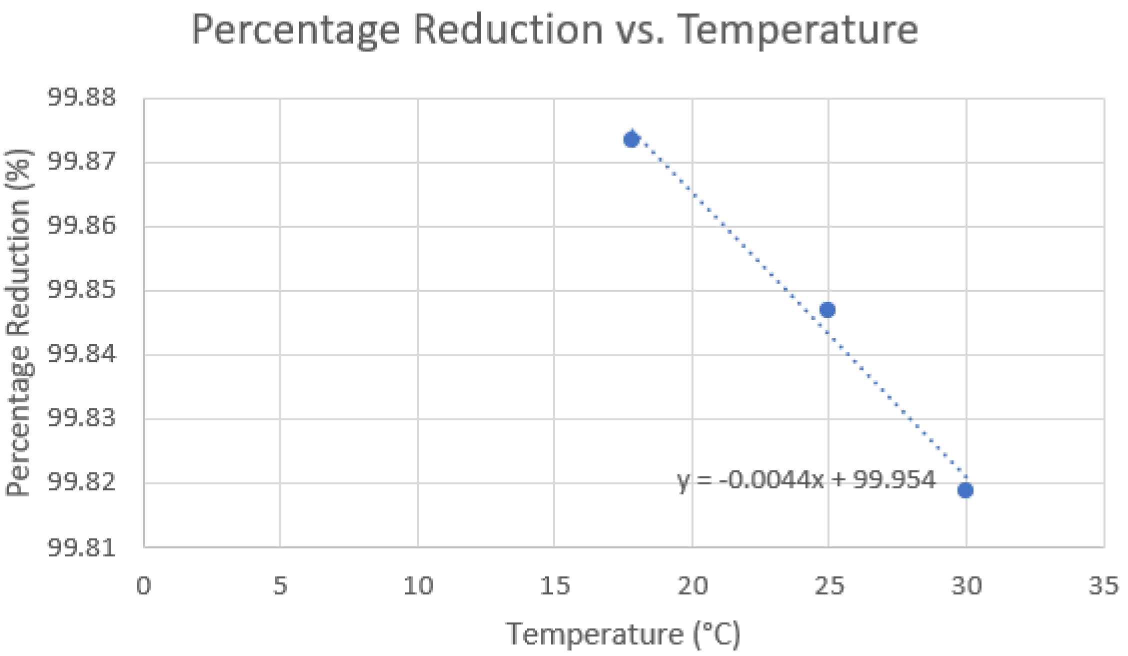


Figure 4: Graph showing the decrease in % Reduction as a function of temperature

When comparing Figure 3 to Figure 4, whilst both are decreasing, it can clearly be seen that the rate of decrease in concentration difference found within the waste stream is greater than that found in the percentage reduction.

2.5. Effect of Nitrate Concentration on EVOFILTER System operation

The following table displays the data gathered from the Nitrate Concentration Variation experiment. Please note that the concentration values displayed are an average of 2 reading taken by the IC. All experiments were conducted at the temperature of 21°C

Table 12: Data from Nitrate Concentration Variation Experiment

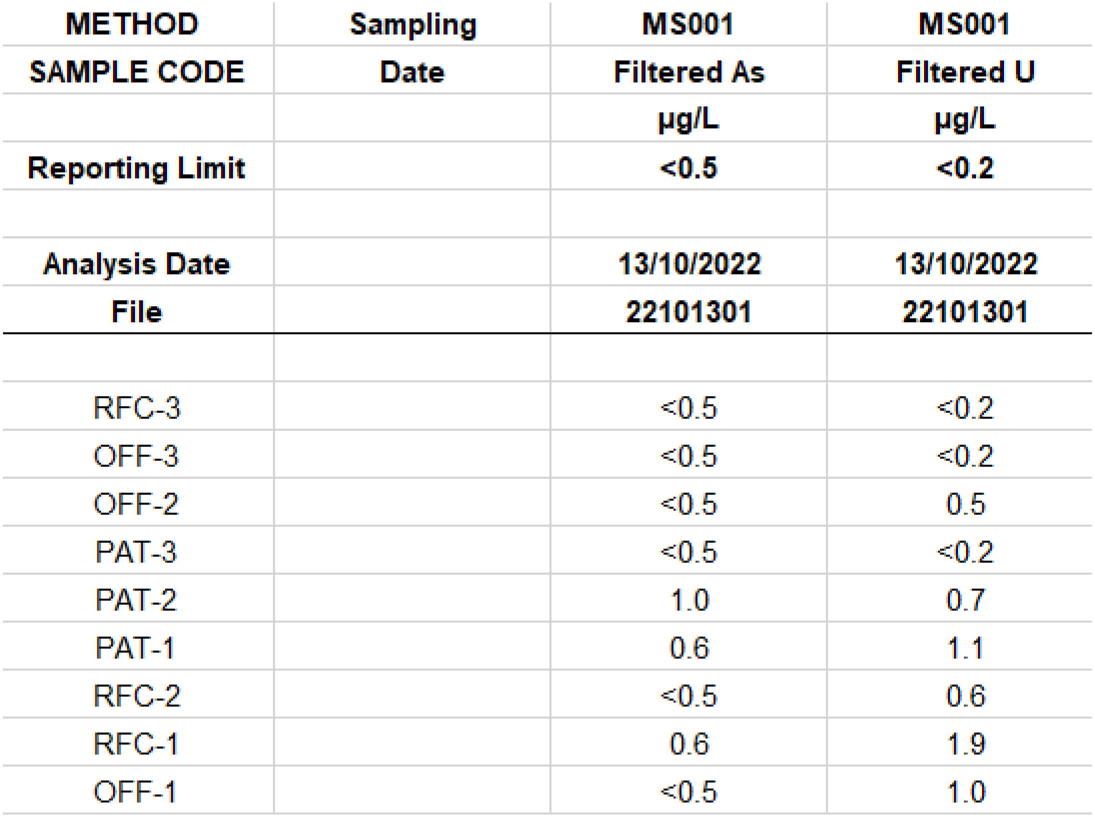
NO_3 Initial Conc. (ppm) [Feed]	Final Concentration (ppm) [Filtered Stream]	Final Concentration (ppm) [Waste Stream]	Concentration Difference (ppm) [between Filtered Stream and Feed]	Concentration Difference (ppm) [between Waste Stream and Feed]	Percentage Removed (%)
76.67	0.0076	111.73	76.66	35.06	99.99
104.16	0.0754	139.66	104.08	35.5	99.93
243	0.438	416	242.562	173	99.82

As Table 12 shows, an increase in concentration led to a decrease in the effectiveness of the filter in the rate of nitrate removal. What should be noted is the sudden spike in the concentration difference between the waste stream and initial concentration, as the initial concentration of the feed goes from 104.16ppm to 243 ppm.

2.6. Concentration Change of Arsenic and Uranium Results

The following table displays the EVOFILTER systems ability to remove Arsenic and Uranium, along with the initial levels of uranium and arsenic found within the real water samples obtained from Pandanus Park. This data was received from MAFRL and not obtained firsthand. (See Appendix Figure C 1 for full report).

Table 13: Arsenic and Uranium concentration found in samples sent to MAFRL



METHOD	Sampling	MS001	MS001
SAMPLE CODE	**Date**	**Filtered As**	**Filtered U**
		µg/L	**µg/L**
Reporting Limit		**<0.5**	**<0.2**
Analysis Date		**13/10/2022**	**13/10/2022**
File		**22101301**	**22101301**
RFC-3		<0.5	<0.2
OFF-3		<0.5	<0.2
OFF-2		<0.5	0.5
PAT-3		<0.5	<0.2
PAT-2		1.0	0.7
PAT-1		0.6	1.1
RFC-2		<0.5	0.6
RFC-1		0.6	1.9
OFF-1		<0.5	1.0

3. Discussion

3.1. General Discussion

A cursory glance at the data presented in the results will shows that the EVOFILTER Reverse Osmosis system is a good solution to filter nitrates in remote WA communities. The system is robust enough to withstand frequent power cuts and continue operating optimally. The effect of varying parameters such as temperature and nitrate concentration within the tested range seem to not vary its effectiveness in removing nitrates by more than 1%, as seen by the fact that all the nitrate removal percentages are above 99%. This could be due to the composition of the RO membrane, or the pre-treatment modules seen in the filter (See Appendix Figure A 6), however this cannot be confirmed as enquiries into the exact composition of the membrane and pre-treatment modules have been fruitless as they are considered trade secrets. However, there are a few anomalies in the data that must be discussed to fully judge its suitability as a method to reduce dangerous nitrate levels in drinking water to safe levels within remote communities such as Pandanus Park.

3.2. Nitrate Retention within the Filter

One of the first discrepancies to discuss is the tendency of the EVOFILTER to retain contaminants within itself. As the current model being tested is a prototype, there is no backwash system added. As a result, as more and more testing was done, the system's ability to was out nitrate ions in the waste stream kept decreasing. This can be seen in the fact that the concentration of the waste stream was not double that of the input stream. If the system did not trap contaminants, with a filtration effectiveness of >99% the concentration of nitrates in the waste stream should be much higher than that seen in the data gathered. This retention of contaminants could lead to faster degeneration of the membrane (Kang et al., 2007; Zaidi & Saleem, 2022) if it is not kept out by the pre-treatment modules. The tendency of the filter to retain nitrates within itself seems to increase as nitrate concentration increases as seen from the concentrations of waste streams from the real water samples to the higher nitrate concentration simulated water samples Table 12. However there seems to be a limit to this, as a large increase in nitrate concentration such as that seen in Table 12 from 104.16 to 243ppm, caused the concentration of the waste stream to go from 35.5 to 173ppm. This means that at an input concentration of 104.16ppm there was a 35% increase in concentration between the waste stream and input stream, whereas at an input concentration 243ppm, there was a 71% increase in the nitrate concentration of the waste stream. However, this should not be the case in a real world scenario. There is also no evidence to show that this retention is not merely a temporary issue that is washed out over time, leading to fluctuations in the levels of concentrations retained within the EVOFILTER system itself. Additionally, the modular nature of the parts of the EVOFILTER means that the parts that would retain nitrates such as the membrane and the pre-treatment capsules would be replaced by wear and tear over time before the build-up ever reaches unsafe levels.

3.2.1 Nitrate levels

The experiments done to test the suitability of the system, involved putting the system through unrealistic operating conditions as compared to a real world scenario. For example, the 3 nitrate concentrations chosen for the Nitrate Variation test. The first chosen concentration of 76.67ppm was chosen as a realistic increase in Nitrate concentration from the 60-63ppm nitrate concentrations obtained from the real water sample, due to reducing water tables. The second concentration of 104.16ppm was chosen to exceed that of the safe drinking limit for adults set by the ADWG. There are communities such as Cosmo Newberry (Figure 1) that suffer from water with nitrate levels that exceed this amount. However, the final concentration of 243ppm was chosen to test the limit of the system. Within remote WA communities, this nitrate concentration is highly unlikely to be found in the drinking water. Running such high nitrate concentration simulated water samples through the system may have proven effective to demonstrate the system's ability to filter out >99% of nitrates, but it also had the unfortunate side effect of clogging up the membrane faster, skewing the data of the other experiments as nitrate variation was an experiment done quite early on. Unfortunately, with only 1 unit and no replacement membrane, it was impossible to determine a correction factor to determine the effect of running unrealistically high nitrate level water through the system.

3.2.2. Temperature

As Table 11 shows, the system is largely unaffected by change in the temperature of the input water in the range of between 17.8°C to 30°C. This range of temperature was chosen, due to the Mediterranean climate of Western Australia. Temperatures in the summer can reach 45°C heating up exposed pipes and bores causing an increase in the temperature of the water being inputted into the EVOFILTER system. However, it also has mild winters where temperatures drop below 20°C cooling down the source water. Temperature is an important factor in affecting the effectiveness of an RO Filter as it can change the properties of water. Research done shows that at lower temperatures, water molecules tend to flow slower allowing it more time to pass through the filter (Abdulmuttaleb et al. 2014). The inverse would also hold true, in that higher temperatures can decrease the effectiveness of an RO filter. However, this effect seems to be limited for the EVOFILTER, which still maintains a nitrate removal % of >99% despite the temperature range. In regard to the effect temperature has on nitrate retention within the filter however, from the unequal slopes of Figure 3 and 4, it can be concluded that higher temperatures can cause greater retention of contaminants within the filter.

3.2.3. Arsenic and Uranium retention within the filter

Table 13 give some interesting insights into the levels of uranium and arsenic within the water samples from Pandanus Park and the resultant change after it had been processed by the EVOFILTER system. Firstly, as Table 13 shows, the samples with the suffix -1 (indicating that it’s water that hasn’t been processed yet by the EVOFILTER) shows a uranium concentration of between 0.6 µg/L to <0.5 µg/L (the detection limit of the equipment) and an arsenic concentration 1.0 µg/L to 1.9 µg/L. These concentrations are much lower than the threshold that the ADWG has deemed as dangerous: 17 µg/L for uranium and 7 µg/L for arsenic (NHMRC, NRMMC, 2011). This shows that these 2 contaminants are not ones that contribute to the unsafe conditions of the drinking water within Pandanus Park. Secondly, when comparing the results of the samples with the suffix of -3 (indicating that its samples from the filtered stream) with the results of the -1 samples, it can be clearly seen that the EVOFILTER system has managed to reduce the concentrations of both arsenic and uranium to below those of the initial water samples. Due to the detection limitations of the mass spectrometry, it is impossible to tell from the results exactly how much of these two contaminants have been removed, as the reading for the filtered stream is too low. A possible method considered to determine this effectiveness was to look at the readings for the waste stream and the determining the amount of arsenic and uranium removed by simply deducting the concentration readings of the -1 samples from the corresponding samples with the suffix of -3 (indicating that they were collected from the waste stream) to determine the concentrations of the filtered stream readings, this was not possible as most of the levels of arsenic and uranium in both the -1, -2, and -3 samples are below the detection limits of the mass spectrometry. However, something else interesting that can be gleamed from Table 13 is that when comparing RFC-2 to RFC-1, it can be seen that both the arsenic and uranium concentrations in the waste stream are lower than that of the input stream. This suggests a retention of both these contaminants within the filter itself (probably due to their larger particle sizes). There was a slight concern that the retention could eventually build up to dangerous levels, however considering the low concentrations, the safe limit stated by the ADWG and the fact that no evidence could be found that the retention isn't washed out over time preventing build-up, it is highly likely that parts of the filter that could retain these trace elements such as the pre-treatment components and the membrane would be replaced before the retention ever becomes a health issue.

3.3. Improvements on the EVOFILTER

As the EVOFILTER being tested in the report is a prototype used to demonstrate the effectiveness of the pre-treatment and RO membrane, it has a few prototypes that make it less suitable for use in Remote WA communities. Such design issues include missing features such as backwash, inability to easily turn the filter on and off with a tap, and the need to use an adapter to plug the machine into a power socket. This is all understandable as the EVOFILTER is a prototype and was designed with a Swiss market in mind. The intermediary to EVODROP has reported that the latest models EVOFILTER will come with new features such as anti-bacterial coating, an Australian power socket plug head, and backwash features along with other features. Another key aspect of the EVOFILTER being improved is the low yield percentage. Whilst unconfirmed, the intermediary has reported that the latest model of the EVOFILTER has a 50% yield percentage.

4. Future Research Considerations

While this study proved that the EVOFILTER is capable of addressing the issue of high nitrate levels within Pandanus Park, all the research was done in lab conditions where all the parameters could be controlled, and multiple assumptions made. A case study must be done by providing EVOFILTER units to a chosen remote WA community such as Pandanus Park. The filters need to operate in field conditions in order to account for other influences such as damage due to the environment, other contaminants, changes to the surroundings in field conditions. Samples taken from this case study taken over a long period of time would be invaluable to proving that the EVOFILTER is suitable for achieving safe water for all. Talks must also be initiated to gauge the willingness and attitude of the residents of remote communities in adopting the EVOFILTER as a solution to treat their drinking water. If the case study proves successful, it can be used as a basis to propagate the expansion of EVOFILTER to all remote communities. However, the source water in each community must be carefully studied as high concentrations of certain contaminants can cause rapid degeneration of RO membranes (Zaidi et al., 2022).

In addition, input water pressure is another factor that can have an effect on the effectiveness of an RO filter (Abdulmuttaleb et al., 2014). An attempt was made to vary the input water pressure, however due to lack of equipment to properly control the input pressure, the system made alarming noises and thus the attempt was aborted in order to preserve the integrity of the system. According to the manual, the system is able to operate with an input pressure of 1.6 to 6 bar. Another test could be done with the proper equipment to check the effect input water pressure would have on the EVOFILTER.

5. Conclusion

This data generated from this project proves that Reverse Osmosis filtration such as that found in the EVOFILTER by EVODROP is a viable method of treating the problem by removing nitrates in the water samples. A method of analysing the level of nitrate contamination was devised using Ion Chromatography after considering a few other options, and the nitrate concentration from the provided water samples from Pandanus Park was determined using the aforementioned analysis method to be around 60ppm. The yield rate of the current model was also determined to be around 25% (a quite low figure) that the newer models have seemingly been improved upon. The filtration method is able to remove >99% of the nitrates in contaminated water rendering it safe for children and adults and operational parameters such as temperature and dissolved solids, which would normally have an effect on RO system seem to have a minimal effect on the EVOFILTERs ability to filter out nitrates (<1%). The fact that the EVOFILTER is unbothered by sudden power outages such as that caused by brown outs that are common in remote communities along with its portable design and effectiveness, make it a suitable method of water filtration in remote locations. Based on the conclusive findings of this thesis, it can be theorized that if the system were to be implemented into remote communities, it would have a large, positive, long term effect not only in adults but also in children and infants.

6. Acknowledgements

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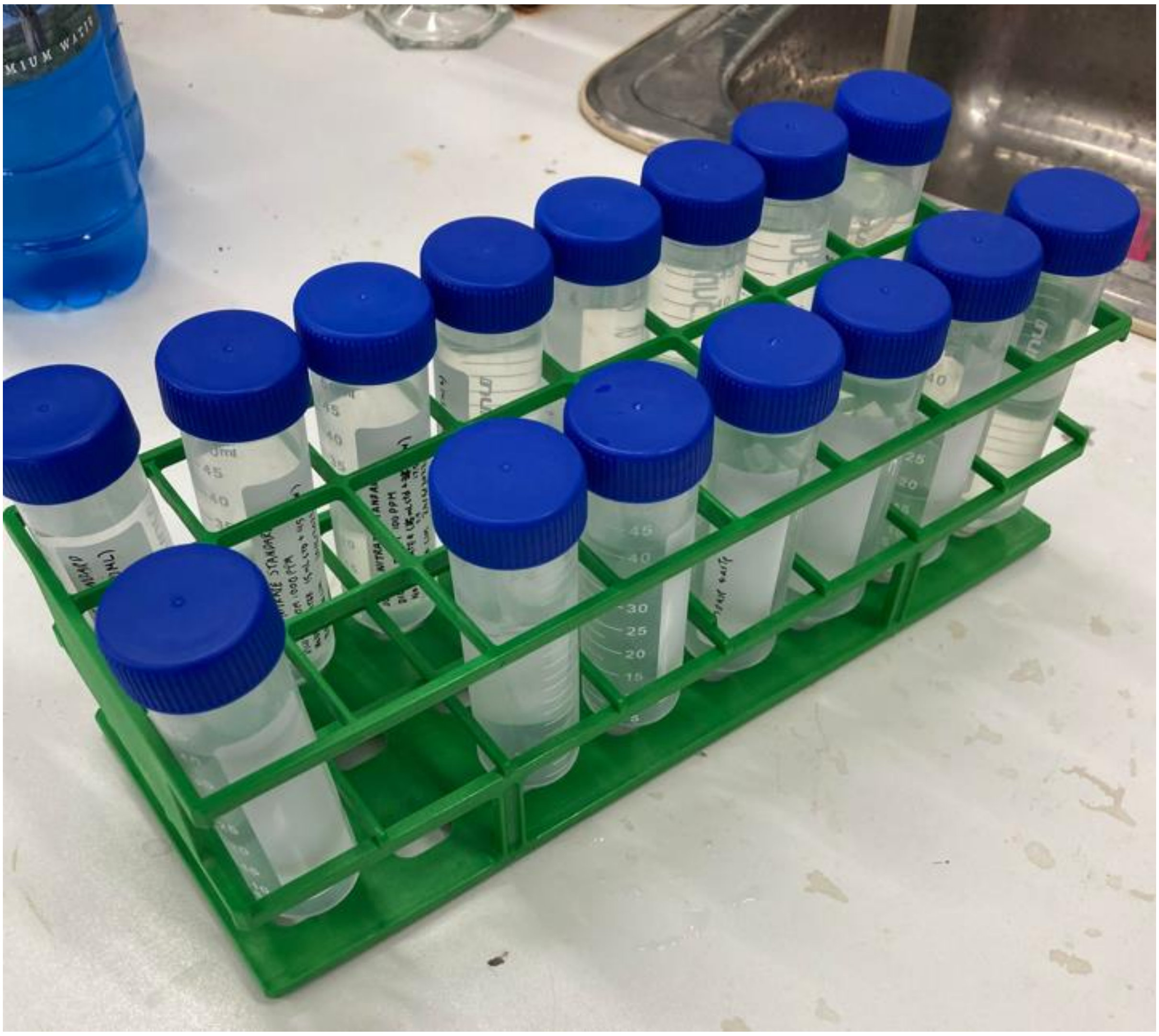
Appendix

Appendix A – Photos



Appendix Figure A 1: Photo of 50ml plastic containers used to store water samples

Appendix Figure A 2: Photo of real water samples received from 3 sources within Pandanus Park

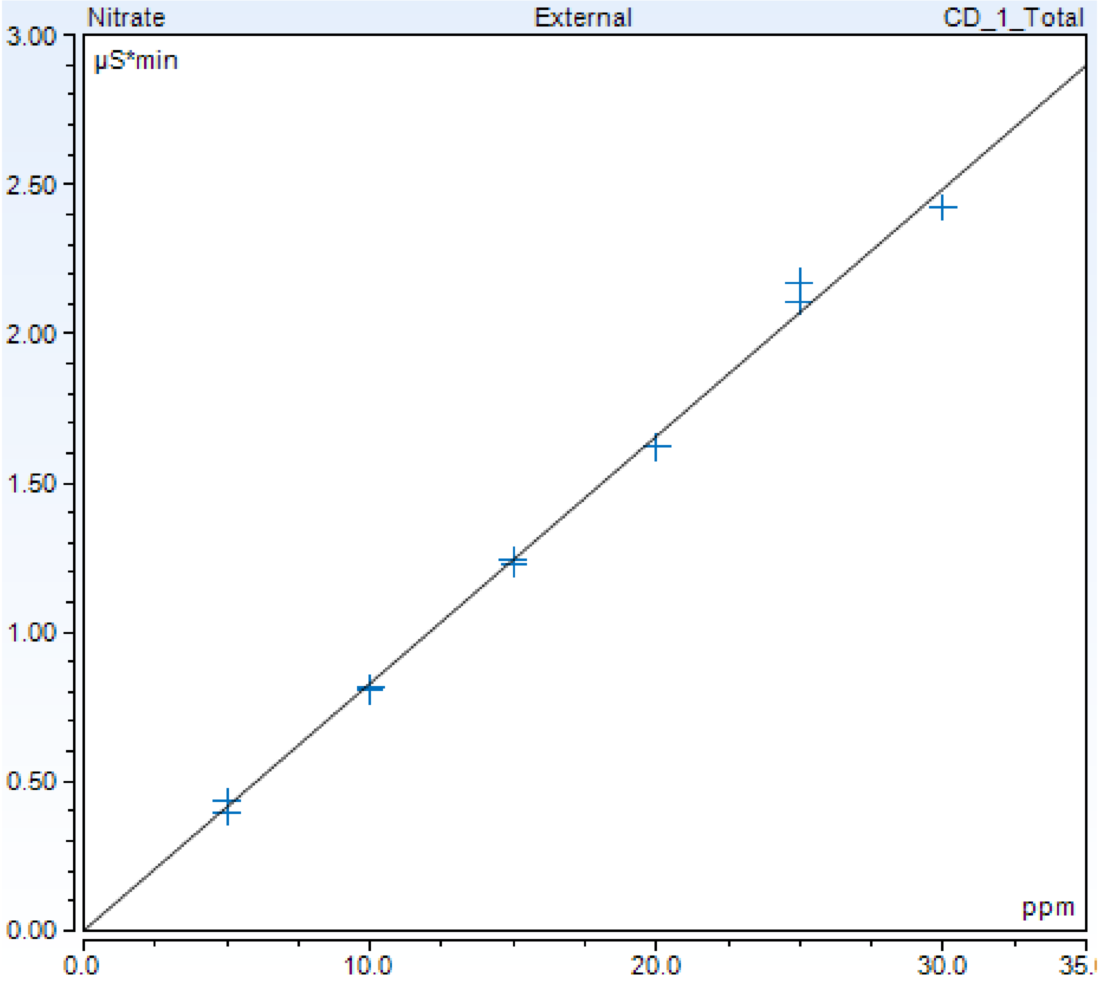
Appendix Figure A 3: Photo of syringe filter used to process water samples for the IC

Appendix Figure A 4: Photo of filter used to obtain Type 1 Ultrapure water

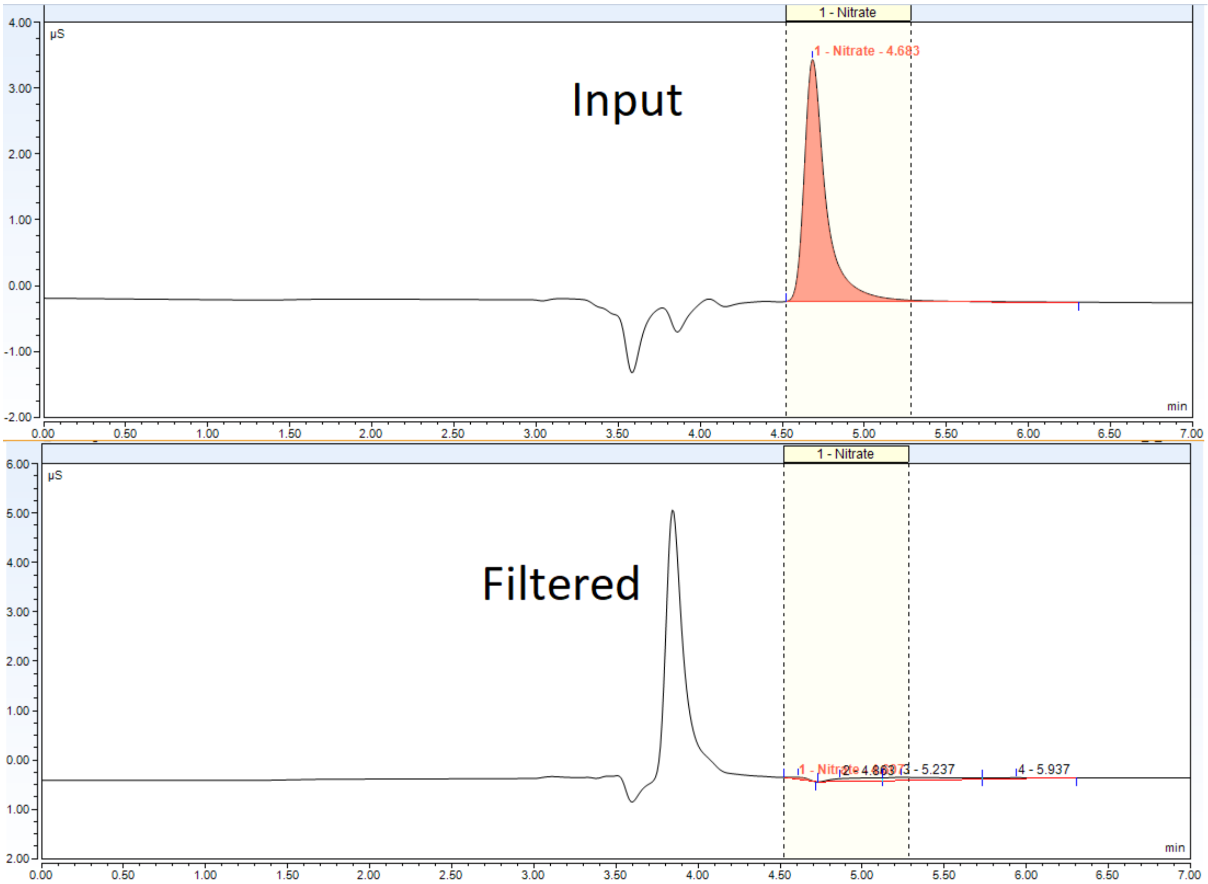
Appendix Figure A 5: Photo of fridge where water samples were stored between experiments with display showing temperature

Appendix Figure A 6: Photo of the interior of EVOFILTER. The top tube contains the RO membrane and the 3 columns at the bottom right house the pre-treatment modules

Appendix B – Graphs

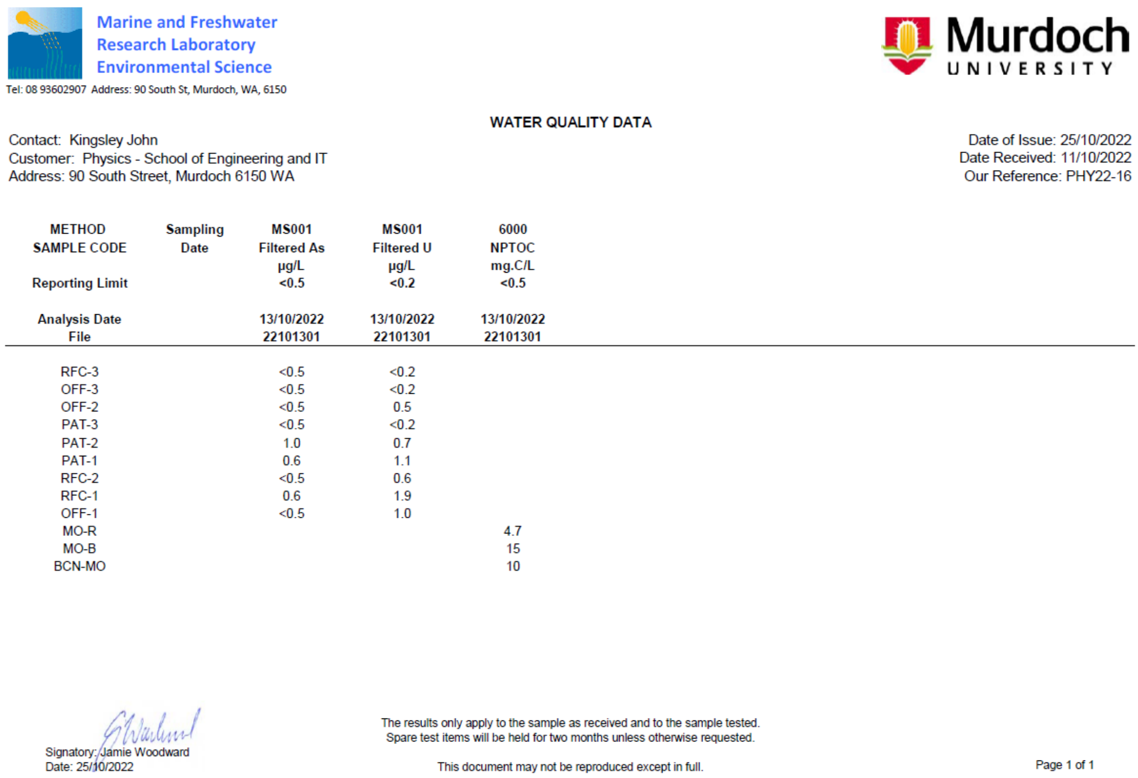


Appendix Figure B 1: Photo of Calibration curve created for the IC



Appendix Figure B 2: Example photo of an IC reading. The top is the reading for an input simulated water sample with a nitrate concentration of 63ppm diluted down to 24ppm. The bottom is the reading of the sample after it has been run through the EVOFILTER

Appendix C – MAFRL Report



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Murdoch UNIVERSITY

WATER QUALITY DATA

Contact: Kingsley John
Customer: Physics - School of Engineering and IT
Address: 90 South Street, Murdoch 6150 WA

Date of Issue: 25/10/2022
Date Received: 11/10/2022
Our Reference: PHY22-16

METHOD **SAMPLE CODE**	**Sampling Date**	**MS001** **Filtered As** **µg/L**	**MS001** **Filtered U** **µg/L**	**6000** **NPTOC** **mg.C/L**
Reporting Limit		**<0.5**	**<0.2**	**<0.5**
Analysis Date		**13/10/2022**	**13/10/2022**	**13/10/2022**
File		**22101301**	**22101301**	**22101301**
RFC-3		<0.5	<0.2	
OFF-3		<0.5	<0.2	
OFF-2		<0.5	0.5	
PAT-3		<0.5	<0.2	
PAT-2		1.0	0.7	
PAT-1		0.6	1.1	
RFC-2		<0.5	0.6	
RFC-1		0.6	1.9	
OFF-1		<0.5	1.0	
MO-R				4.7
MO-B				15
BCN-MO				10

Signatory: Jamie Woodward
Date: 25/10/2022

The results only apply to the sample as received and to the sample tested.
Spare test items will be held for two months unless otherwise requested.

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Page 1 of 1

Appendix Figure C 1: Lab Report from MAFRL showing Arsenic and Uranium concentrations in water sample. The bottom 3 rows should be discounted