Assessment of small-scale desalination by capacitive deionization for horticulture on the Northern Adelaide Plains

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Executive summary

About a third of South Australia's horticulture produce comes from the Northern Adelaide Plains (NAP) and is valued at over $340 million per year. Production in the region has the potential to grow significantly and to meet increasing demands for food locally and potentially for international export. However, the sustainability of these industries is challenged by the quality of the available water supplies. Current supplied reclaimed waters to the NAP are brackish. Groundwater resources in the region, particularly in the northern reaches, have elevated salinity levels. The project was conducted to evaluate the potential of a low cost, (technology and operations) emerging desalination technology called Capacitive Deionization (CDI). In this study, field-based investigations were conducted using a small-scale research and development CDI unit of the University of South Australia to identify potential benefits of the technology for horticulture industries of the Northern Adelaide Plains (NAP).

The CDI unit was trialled at two industry locations. The first was at the Bolivar wastewater treatment plant, further treating reclaimed water for removal of salts. The second was at a major hydroponics industry, treating a slightly brackish groundwater to remove salts to that industry's water quality requirements. The test CDI unit used had a flow rate capacity of up to 4 kL/day. The slightly brackish groundwater had a total dissolved solids (TDS) level of about 800 mg/L and reclaimed water had a TDS of about 1100 mg/L. The highest salt removal efficiency of the CDI unit was around 50% for reclaimed water (average 30%) and 57% for groundwater (average 30%). Water recovery was 64% for reclaimed water and 72% for groundwater. Removals of various cations and anions in the source waters by CDI are detailed in this report. The removal of boron by the trial CDI unit was not evident in this study. Organic fouling of the CDI electrodes was experienced with the treatment of reclaimed water and significantly reduced the efficiency of the CDI operation. This required enhanced chemical cleaning of the CDI unit. The long-term impacts of this on CDI efficiency requires further investigation.

These salt removal efficiencies of the test CDI unit indicate potential application for some soil based horticultural practices, where the removal rates could improve water quality to tolerable levels for various crops. However, this study indicated that the technology would not be suited for advanced hydroponics industries which currently use waters with very low TDS levels and rely on Reverse Osmosis (RO) technologies. However, new generation, commercially sourced CDI technologies might have improved capabilities to the test unit used in this investigation. Where considered for application in the NAP, these units should be pilot tested for capability and reliability of performance.

The investigation identified existing governance arrangements for the management and disposal of RO derived brine wastewaters in the NAP. Relevant policies and regulations of the South Australian Environment Protection Authority referring to RO and wastewater management operations are summarised in this report. Currently only the major hydroponics industries require licencing of RO operations, based on their water processing volumes and on brine wastewater production. Under the current legislative framework, the significance of impacts of non-licensed RO operations of less than 200 kL/d process water and associated brine discharges on receiving environments of the NAP are unknown and therefore, may be of concern. Consideration should be made to licence all RO operations in order to monitor brine waste production, however, this should be based on low-cost licencing requirements in order to gain the support and co-operation of industry. Studies should be undertaken into the sustainable and cost-effective management of brine wastewater.

Global manufacturers of CDI technologies were identified. CDI based technologies include CapDI (Voltea BV Netherlands) designed for soil-based horticulture; and Radial Deionizing Super Capacitor Technology (RDITM, Atlantis, USA) designed for treatment of 5,000 to 20,000 mg/L TDS saline waters, as well as treatment of brine wastewaters. It is recommended that such manufacturer claimed performances be validated by locally applied pilot plant trials prior to implementation for horticulture production; and that the reliability, maintenance requirements and on-going technical services provisions be given due consideration.

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1 Introduction

The Northern Adelaide Plains (NAP) region is one of significant economic importance with a horticultural industry producing $340 million worth of produce at the farm gate in 2014/15 (PIRSA 2016). This contributed to approximately 34 percent of South Australia's total horticultural production value. The region extends from Pooraka to Gawler, Mallala and Buckland Park, encompassing Virginia and Angle Vale. The region is renowned for its high quality fresh produce, year-round consistent supply, proximity to market, ethnic and cultural diversity, and family producers.

The availability of water has been identified as a significant barrier to growth. A recent report by Goyder Institute for Water Research identified current water availability and future potential to increase supply to the NAP (Goyder Institute for Water Research 2016). Recycled water sourced from the Bolivar Wastewater Treatment Plant (WWTP) is distributed via the Virginia Pipeline Scheme (VPS). The Bolivar WWTP processes 49 GL annually, with SA Water delivering 17 GL to horticulturists that have access to VPS. Not all generated water is suitable for recycling due to salinity and other water quality factors. An upgrade to Bolivar WWTP will generate an additional 20 GL of recycled water, bringing the total amount of recycled water available for irrigation to 39.5 GL (Goyder Institute for Water Research 2016). During 2013/2014, groundwater extractions from T1 and T2 aquifers in the NAP Prescribed Wells Area (PWA) totalled 12,110 ML/year - well-below the allocation of 27,122 ML per/year and the sustainable extraction limits of 19,420-20,640 ML/year (Watt et al. 2014). This could allow for some growth in groundwater use within allocated volumes, especially from the T2 aquifer. There is a significant volume of water in the tertiary aquifer to the north of the NAP PWA but salinity levels are higher (~3000 ppm or more) than those used for irrigation of most horticultural crops and would require desalination.

Desalination of water for agriculture has a number of advantages including tailored salinity for irrigation water, reliable supply, consistency of agricultural product quality, potential for higher product sale price due to high quality and supply reliability and the opportunity to recover saline soils by irrigation with high quality water (Burn et al. 2015). The application would be more feasible when the saline water source is available near agricultural sites, in conjunction with cost effective desalination technologies, where safe and low-cost brine disposal options are available.

In Australia, desalination is predominantly achieved by reverse osmosis (RO) through which most organic and inorganic constituents including salts, are removed. Generally, RO involves high capital and operating costs. However, these costs vary according to source water quality and scale of desalination. Capacitive deionization (CDI) is an emerging, purported lower energy, electrochemical desalination technique which has been trialled for the treatment of brackish water in Alice Springs, Australia (Mossad et al. 2013, Mossad and Zou 2012). The potential advantages of CDI over conventional technologies include lower operating and capital costs, lower energy consumption, reduced brine volumes (2-4 times more concentrated compared to RO, assuming a single CDI treatment pass), relatively easy maintenance, operation with minimum technical expertise and ability to be operated using readily available renewable energy sources such as solar via photovoltaic cells. CDI technology appears to be in continual development and growth, though some companies failed or abandoned the CDI market (Weinstein and Dash, 2013). At the time of this project, a range of companies were listed on internet websites as potential suppliers of CDI technologies including, Aqua EWP (USA), Atlantis Technologies (USA), Enpar Technologies Inc. (Canada), Idropan Australia (Italy) and Voltea BV (Netherlands) (see Appendix A for more details).

1.1 General aim of the project

The aim of this project was to investigate the potential of CDI technology for desalination of brackish water of the Northern Adelaide Plains for use by the horticulture industry. This was investigated by conducting small-scale CDI trials on a brackish groundwater and Bolivar DAFF (Dissolved Air Flotation in Filter) reclaimed water, for preliminary assessment of potential use for horticultural production.

1.2 Scope of the research

This project, through experimental laboratory and field trials, investigated the following:

- whether CDI technology can desalinate reclaimed water and groundwater of the Northern Adelaide Plains to levels that are suitable for fit for purpose use in the horticulture industry;
- the comparative energy use and costs of water supply associated with utilising the available CDI unit; and
- the potential suitability of treated water through the CDI treatment for horticulture water needs.

Specifically, the project investigated CDI treatment for potential application for irrigated horticultural areas around Virginia and Two Wells South Australia (Figure 1). This project investigated CDI technology to desalinate (1) Bolivar WWTP DAFF recycled domestic wastewater (tertiary [alum] DAFF/chlorinated treated wastewater post activated sludge) and (2) bore water of P'Petual Holdings Pty Ltd with a TDS of ~ 700-800 mg/L.

During the initial stages of the project, two CDI units were understood to be available for trialling, one of which was owned by the University of South Australia (UniSA) and the other which was owned by a private company that markets CDI technology in Australia. Subsequently, the private company did not supply a unit for trialling and so only the UniSA was used. This unit had been extensively used for CDI research and development work at UniSA. Reassessment of the CDI's maximum efficiencies for this project showed performance at equivalent flow rates to be below previous applications, and hence flow rates were lowered for these project trials to achieve maximum TDS removal efficiencies of 50-57%. It can be expected that new and modern units would provide better efficiency in treatment performances. i.e. higher flow rates would provide for the same TDS removals.

1.3 Project objectives

The study investigated the potential of CDI as a desalination technology for the horticulture industry, with the following objectives:

- To conduct a preliminary field trial in the NAP using a research and development CDI unit to assess the potential application of CDI for desalination of bore water for intensive horticulture.
- To conduct preliminary trials at the Bolivar WWTP DAFF plant using a research and development CDI unit to assess CDI for desalination of tertiary treated reclaimed water for intensive horticulture.
- To provide information on the potential of CDI technologies for water supply for the horticulture industries of the NAP, based on currently available CDI technologies.
- To investigate reported applications and costs of commercially available CDI desalination technology for horticulture, including water supply and energy costs. This includes a comparison of establishment and operational costs with RO desalination.
- To provide information on current governance and policies related to desalination operations used by the horticultural industry in the NAP region and information that supports the future development of governance/regulatory needs related to brine disposal.
- To identify and assess regulation and governance issues associated with desalination by horticultural enterprises in the NAP region with regards to disposal of brine.

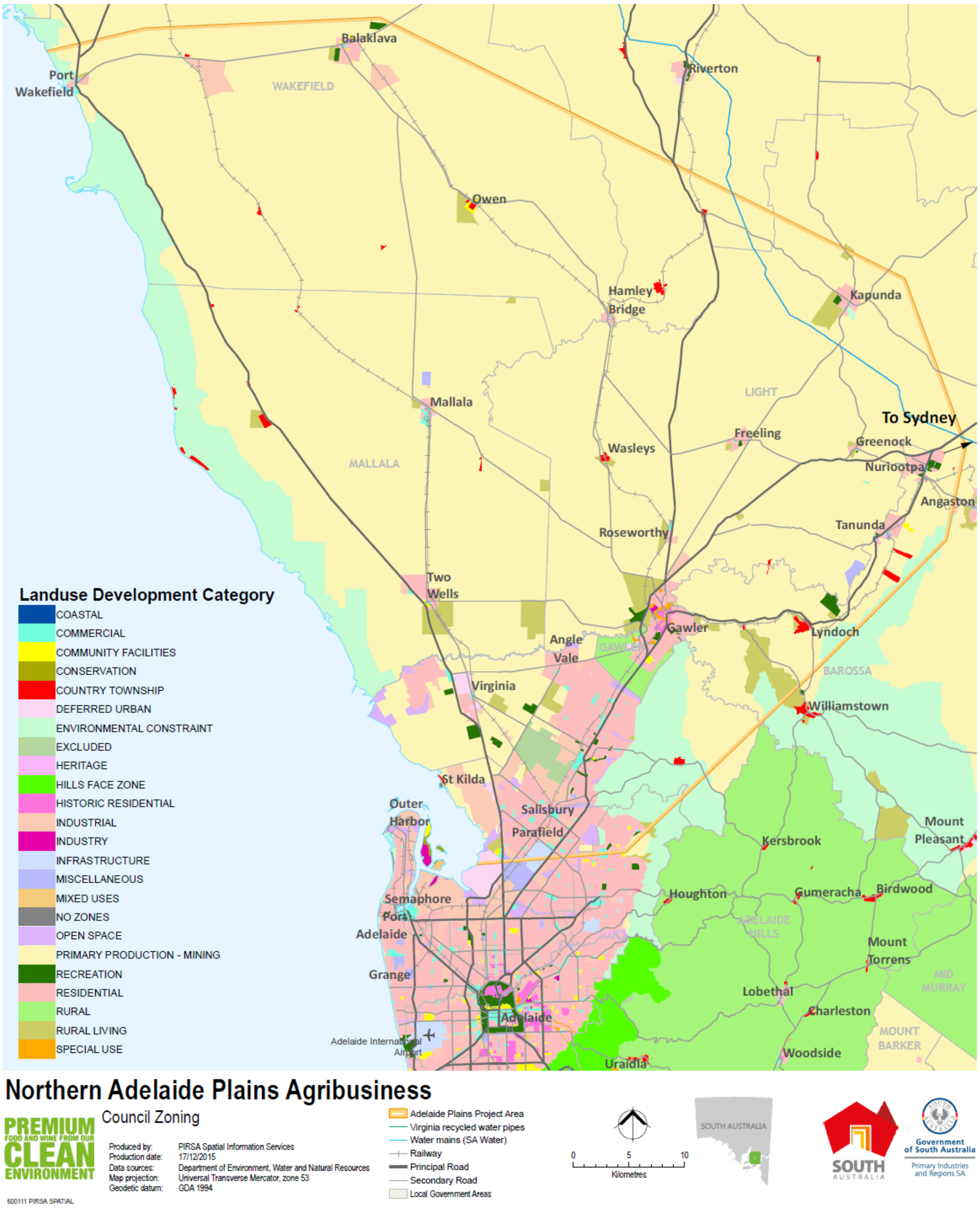


Figure 1. The irrigated horticultural areas around Virginia and Two Wells.

1.4 Significance of the project

This preliminary study investigated the potential feasibility of CDI technology as a low-cost water desalination option for the horticulture industry of the NAP region. The study aimed to provide information to support decision-making by stakeholders and government agencies on desalination technology options including CDI systems & manufacturer(s) for the intensive horticulture industry. Desalination is increasing being applied by the horticulture industry in the NAP based on information provided by companies that supply and install RO plants. These have been reported to have 5 to 9 kL/hr treatment capacities for the hydroponics industry. RO tends to be an 'all removal treatment process', and alternative treatment processes that are based on partial removals of constituents at lower cost might prove beneficial. Hence, this project aimed to provide understanding of the potential of CDI technologies for water supply for the horticulture industries of the NAP.

2 Key project outcomes

This section provides a summary of the key findings of the project and recommendations. The field trials were first carried out at the Bolivar WWTP DAFF plant for investigation of CDI treatment of reclaimed water (TDS ~1000 mg/L) and then at P'Petual Holdings Pty Ltd, a hydroponics enterprise located in Buckland Park, for investigation of slightly brackish groundwater (TDS ~700-800 mg/L). The CDI unit used for the trial was owned by UniSA that had been acquired in 2008. This unit was used for comparative assessment of treatment of reclaimed water and bore waters. Its efficiency was lower than would be expected from a modern CDI system. During the project, a domestic CDI supplier had offered the loan of one of their demonstration units for the purposes of the studies planned. However, this offer was withdrawn during the project.

For reclaimed water desalination using the CDI unit, pre-treatment for removal of dissolved organic matter by adsorption to granulated activated carbon (GAC) was used as a precautionary measure with the aim to protect the CDI unit from excessive fouling from organics. The comparative average and highest desalination capacities and energy consumption of the CDI unit were also determined for the two types of waters that were desalinated without pre-treatment.

As part of this project, existing governance, regulation, and guidelines for desalination practices in the NAP were investigated through consultation with the South Australian Environmental Protection Authority (SA EPA), irrigation industries and a RO user. Costs of current desalination technologies used in the NAP, mainly RO and pre-treatment technologies [microfiltration (MF) and ultrafiltration (UF)] were obtained from two major RO technology providers Integra and Fresh Water Systems and were compared with estimate costs provided by AQUA EWP for their marketed CDI units. Identified challenges in implementing CDI in the NAP and recommendations for governance are included.

2.1 Findings from CDI trials conducted on reclaimed water and bore water

- The salt removal efficiency was measured over a 24 hour period at a flow rate of about 1-2 L/min. For Bolivar reclaimed water (average ~1100 mg/L TDS) with GAC pre-treatment used to remove dissolved organic carbon (DOC), the average efficiency dropped from approximately 50% to 30%. For groundwater (700-800 mg/L TDS), no pre-treatment was required, and the average efficiency dropped from 35% in the first hour to between 15–20% for the remaining period.
- Organic fouling significantly reduced the efficiency of the CDI unit. The salt removal efficiency with reclaimed water dropped from 30% to 10% in 11 hours in the absence of DOC removal (GAC pre-treatment) prior to desalination, with frequent chemical cleaning needed.
- Water recovery/yield from reclaimed water was 64% with pre-treatment and 59% without pre-treatment. For groundwater, desalination the water recovery was approximately 72%.
- Chemical cleaning with citric acid and sodium hydroxide recovered CDI salt removal efficiency. For reclaimed water, CDI cleaning solutions used were 2% citric acid to remove scaling and 2% sodium hydroxide to remove organic fouling. However, the impact of sodium hydroxide on the unit may have been detrimental (further information is provided below). Groundwater desalination showed simpler cleaning needs due to absence of organic fouling where the CDI performance was re-established by cleaning with 1% citric acid only.
- The CDI has low water supply pressure (20–40 psig) requirements and was supplied with feed using mains pressure at Bolivar WWTP. A Davy centrifugal pump (0.78 kW) was used to supply feed water at P'Petual Holdings since groundwater was fed from a storage tank. The average energy consumption by the CDI unit used for the study was ~3.5 kWh/kL.
- Horticultural enterprises have strict control of water quality and it appears they require desalinated TDS to be <100 mg/L (e.g. for advanced hydroponics industries). This was not able to be achieved by the trial CDI unit in a single pass of treatment. However, greater TDS removal with CDI technology would be

achievable by application of more units in series, and ultimately, then achieving a target TDS level (that might be suitable for a particular industry purpose). The volume of brine waste would increase accordingly and final product waters would subsequently become less. For example, assuming a CDI water recovery of 75-80% (20-25% wastewater) and an optimum TDS removal performance of 85%, a first pass CDI treatment of a bore water of TDS of 1400 mg/L, would give a product water exceeding 210 mg/L. A second pass (in series CDI) would give a target TDS of less than 100 mg/L. If a second, in series treatment is used then this would lead to a product water recovery of about ~60%, with higher energy requirements. A lower source water TDS of 700-800 mg/L would lead to a first pass CDI treated water of ~100 mg/L. Higher TDS source waters than 1400mg/L (e.g. bore waters north of the Light River) would likely require in series or multistage treatment to achieve TDS levels as currently of waters using RO. Treatment systems can be designed to accommodate input water quality and the desired output quality and quantity by using larger units or arranging small-scale units in parallel.

2.2 Governance and regulation

- Licensing of desalination plants is done based on site specific risk management considering the location, volumes of water processed/discharged and the impact of discharges on the receiving environment. An SA EPA licence is required for RO operations where production of desalinated water exceeds 200 kL/day and, where a plant produces more than 2 ML/year of wastewater (*Environment Protection Act 1993,* Schedule 1 (8)(6a)). This includes an underground desalination plant and a number of underground desalination plants that in aggregate have a production capacity exceeding 200 kL/day of desalinated water, within any 1 km^2 area. A licence is not required where a plant disposes all of its wastewaters to a wastewater management system that is the subject of a licence.
- There is currently limited information for management of brine and its disposal for desalination systems smaller than 200 kL/day. Brine is considered as wastewater and treated as such accordingly. e.g. treatment might include septic tanks. Evaporation ponds with HDPE lining are a brine disposal option for large scale RO operations.

2.3 Current challenges for implementation of desalination in the NAP and recommendations for governance

- There are few suppliers of CDI technology in Australia and the nature of local pre- and post-sales services is unknown. The suitability for implementation of CDI in the NAP for horticulture would depend on CAPEX and operational and maintenance costs (including energy) along with a range of factors including groundwater salinity level, the extent of desalination required, actual performance of the CDI technology in context of source water quality (in addition to TDS), provision and reliability of after sales support and service. It is also recommended to consider site-specific requirements through detailed pilot scale study prior to any medium and large-scale implementation. Small scale CDI units might be purchased for fit-for-purpose uses in the NAP where water needs are low (several thousand litres per day) and brackish bore water is readily available at TDS levels that allow for single unit (single pass) treatment.
- Using CDI desalination for reclaimed water appears to need pre-treatment for removal of dissolved organics to bore water levels. The pre-treatment options should be considered, including their ongoing costs, as well as investigation of CDI technology such as marketed by Voltea BV (CapDI) that specifies a DOC limit of 15 mg/L, which is near to or higher than Bolivar DAFF reclaimed levels.
- Development and provision by government-sourced (regulatory - state and local) information (e.g. fact sheets), guidelines and regulation on desalination application with brine management based on the size of desalination plants, is recommended. A broad range of communication approaches, including consultation with local viticulture and horticulture groups and associations is further recommended.
- For desalination operations of less than 200 kL/day (that do not require current SA EPA licensed approval) feasibility assessment of installation of networked larger scale evaporation ponds (managed

by government- state and local) for localised, precinct hydroponic farms is suggested. Mapping of the distributions of small and medium scale desalination plants in the NAP is also suggested to enable identification of suitable locations for such lagoons.

- Mapping of all RO applications in the NAP is recommended to facilitate monitoring of adopted brine disposal procedures and assess the sustainability of approaches applied. Stakeholder information provided includes that brine discharge is to saline quaternary aquifer and evaporation basin systems. Other than SA EPA licenced approved RO systems, brine management and discharge procedures and their impacts on receiving environments are largely unknown.

2.4 Companies that manufacture/supply CDI technology

Idropan Australia markets small scale modules that can treat saline waters up to 1250 ppm and each unit produces up to ~ 2000 L/day. An assembly of several such modules can achieve higher production capacities. Currently available technology is purported to be able to treat and supply waters at industry/commercial scale flow rates. For instance, AQUA EWP markets a P8 model that is stated to treat water to 2.4 kL/hr, Voltea BV markets CDI CapDI© modules that are claimed to be able to treat to 20 kL/hr and Atlantis Technologies market their RDI© systems as able to treat water in single module to ~23kL/h [with more modules up to 1000 gpm (or ~230 kL/h)]. These levels of supply rates would meet the supply needs of the horticulture industries of the NAP, providing that treated water quality meets industry requirements.

The following sections detail the methodologies, results and analyses undertaken.

3 CDI trial methodology

3.1 Trial site selection

Field site selection was based on a suitable bore water availability (brackish bore water) with necessary infrastructure such as established pipelines, power supply, security, brine disposal (existing RO treatment in place).

With regards to the testing of the CDI units, key factors in site selection were:

- Power supply (240 V, AC, 15 A single-phase), and with accessible connection and a circuit breaker
- Input water pressure regulation
- Access to clean water supply for cleaning with citric acid solution and NaOH solution
- Existing brine disposal infrastructure/option
- A sheltered area/shed for the CDI unit and associated equipment and testing instruments
- Supportive landholder/grower

Considering the above criteria, the selected test locations were:

Bolivar WWTP DAFF plant for testing of the CDI unit to treat reclaimed water (post activated sludge and tertiary treated – coagulation and flocculation by alum and chlorination).

P'Petual Holdings Pty Ltd, a hydroponics enterprise located in Buckland Park, South Australia (NAP PWA), which at the time of this study used a slightly brackish (~700 mg/L TDS) bore water supply.

The initial project plan included selection of a NAP test site with groundwater salinity of 1650 ppm where there was established infrastructure for concentrated brine disposal. P'Petual Holdings Pty Ltd was highly supportive of the study and was selected for testing of the trial CDI unit for the treatment of the bore water supply. P'Petual Holdings operates two reverse osmosis plants with sand/anthracite and ultrafiltration pre-treatment steps. It has a HDPE lined evaporation basin for brine wastewater (BWEB) disposal. In the trial conducted, product water from the CDI test unit was returned to a raw bore water storage tank that subsequently underwent RO treatment and CDI brine wastewater was disposed to the BWEB. The CDI product water management for this trial was selected based on the low product volumes produced and the need for strict control of water quality (low TDS, nutrient levels and pest risk minimisation).

Allwater was also highly supportive of this project enabling trials to be conducted at the Bolivar DAFF plant. The CDI product water and brine were directed back to the DAFF plant's wastewater.

In both cases, no brine discharge costs were incurred for this project. Industry requirements for Welfare, Health and Safety compliances including risk assessments and standard operating procedures were met as specified, prior to CDI trial commencement. Test flow rates were below 10 L/min and citric acid (0.01M) was used for cleaning, stored at <20 L volume. Waste water was discharged to a recovery tank to be neutralised before being directed to DAFF plant's waste water.

3.2 Experimental methods

The following section details the equipment and the procedures that were used in the trials.

3.2.1 SPECIFICATIONS OF THE CDI SYSTEM

The specifications of the UniSA trial CDI are as follows.

Supply voltage:	240 V, AC, 15 A single-phase
Individual electrode cell voltage:	1.5 V DC
No of electrode pairs:	100
Electrode material:	Activated carbon
Weight of Material:	1.354 kg
Operating conditions	
Flow rate:	1–9 L/min (1.2–10.8 kL/day)
Source water concentration:	500–10,000 ppm
Input pressure:	20-40 PSIG
Types of ions treated:	Sodium, magnesium, calcium, ferric, arsenic,
	chloride, bromide, nitrate, fluoride, sulphate
Remarks:	No silica scaling on electrodes
Operational temperatures:	20–50 °C
Pre-filtration requirements:	Cartridge filter rated for 10-25 microns

Note: this CDI unit is a research and development unit that had been used in laboratory and field-based trials since 2008. Assessment of the unit during this project showed optimum TDS removal efficiency of approximately 50% for reclaimed water (~ at ~1.5 L/min) and 57% for bore water (700-800 mg/L TDS, at ~2 L/min). In comparison Mossad et al. (2013) found higher optimum TDS removal efficiencies of about 65% for bore water (brackish groundwater, ~1500 mg/L TDS, at 9 L/min, to achieve a target TDS of 500 mg/L and 85% for the same water at 2 L/min). Average TDS mg/L in process water would be less. New CDI technology is expected to provide higher efficiency desalination performances, and it is recommended that any consideration for implementation of CDI technology is in consultation with CDI manufacturers and suppliers and only with pilot scale trials being conducted to confirm treatment performances.

3.2.2 EXPERIMENTAL PROCESSES

The trials were conducted in two phases:

- Phase1 - trials at Bolivar DAFF plant for CDI treatment of reclaimed water with TDS ~ 1000 mg/L
- Phase2 - trials at P'Petual Holdings for CDI treatment of bore water with TDS ~700-800 mg/L

For each phase, the following tests were carried out:

1. Salt removal capacity and efficiency at known input (source water) salinity levels.
2. Desalination performance at various flow rates to meet various water quality targets. The CDI was flushed with 0.01 M citric acid after testing at each flow rate.
3. 24 h operation at a selected flow rate to identify when chemical cleaning should be done.
4. Continuous operation with cleaning. Volumes of product water, brine waste and chemical cleaning solutions were recorded.
5. Adequate pre-filtration was considered when reclaimed water was used as the feed water supply. The salt removal at a selected flow rate was studied with pre-treatment (activated carbon filter) either connected or disconnected.
6. The power consumption by CDI at each flow rate and over 24 h period at a selected flow rate.

The trial CDI unit works in 150 sec cycles, which included 30 sec of idling, 30 sec of brine discharge and 90 sec of product discharge. The TDS of the product and brine were monitored and recorded on site using a potable conductivity meter (Hatch). CDI was operated for 1 h before a sample was taken. The average salinity of the product water during a 1 h period as well as the lowest product salinity in the last desalination-regeneration cycle was recorded.

The salt removal efficiency was calculated as:

$$(C_o - C) \times 100/C_o$$

where C_o and C are the feed and product TDS (mg/L). The power consumption was monitored using potable power meter (Power-Mate 15Amp). Data was recorded every 10 seconds over 5-10 charge-discharge cycles.

The power consumption was manually recorded every 10 s for a prescribed period and the amount of water that was produced during the same period were recorded. The power data were plotted against time duration, which was integrated to obtain the energy consumption.

Water quality analyses were performed by ALS Environmental Services, a NATA accredited laboratory. The analyses included major cations and anions, N and P nutrients, organics, metals, alkalinity, hardness and boron.

3.2.3 PRE-TREATMENT FOR DISSOLVED ORGANIC CARBON REMOVAL

Considering the water quality analyses reports it was evident that the concentration of DOC could affect the desalination performance by CDI, also reported by (Mossad and Zou 2013b). For the Bolivar DAFF trial, a pre-treatment step was implemented consisting of a filter with granular activated carbon (GAC), supplied by Filchem, Australia. The filter details are as follows:

Length:	2 m
Diameter of the pipe:	250 mm
Ends:	Flanged, stainless steel mesh, 2 mm
Orientation:	Inclined to a vertical height of 550 mm from the ground.
GAC:	Weight - 35 kg,
	Size - 1-1.2 mm

Iodine number - 900 mg/g min

The GAC was pre washed to remove fine materials before being filled into the column. The bottom of the column was filled with gravel (5- 10 mm) to a height of 20 cm. After assembling, the GAC filter was flushed with potable water for 1 h to further remove fine carbon particles.

3.2.4 PROCESS FLOW DESIGN AND INSTRUMENTATION

A process flow diagram (Figure 2) shows the layout of the CDI and associated equipment installed at the DAFF plant. At the water inflow to the CDI unit, a non-return valve was installed. The GAC column was fed with DAFF product water (without chlorination) under the supply pressure of ~ 25 psig. The cartridge filter (10 µm) was installed prior to the CDI unit to trap any carbon particles that could be released from the GAC filter. The circulation of cleaning reagents was done using the Davy pump (0.78 kW) where the feed was connected to the feed sampling tap. For the trials at P'Petual Holdings, the GAC filter was not used as the DOC concentration in bore water was very low, i.e. ~0.7 mg/L.

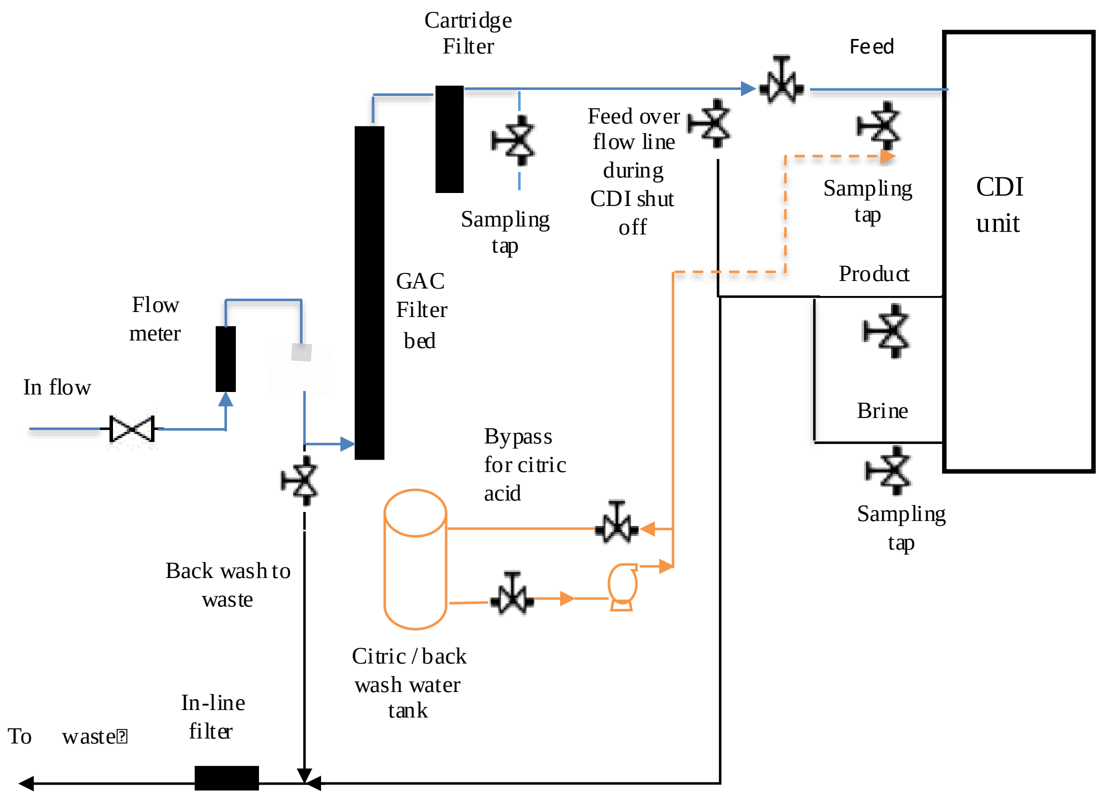


Figure 2. Process flow diagram.

4 Results: desalination of reclaimed water by capacitive deionization

The CDI desalination trial of reclaimed water was initially conducted using pre-treatment by GAC filtration. Firstly, the efficiency of the designed GAC filter in removing dissolved organic carbon was determined. Then salt removal performance at different flow rates was studied and desalination at a selected flow rate for 24 h to identify when best to carry out chemical cleaning. Following this, the GAC filter was disconnected and CDI desalination trial continued at the same flow rate for 24 h period, to assess the need for the GAC column.

4.1 Removal of dissolved organic carbon (DOC)

The removal of dissolved organics was assessed at different flow rates to establish a suitable contact time for significant removal of DOC. The results are listed in Table 1 and Figure 3 (see Appendix B for detailed results). Accordingly, a contact time of 20 min that resulted in 99% DOC removal was selected for preliminary trials. The selected GAC contact time (20 min) required a flow rate of 1.5 L/min. A higher flow rate would have required an intermediate feed tank for storage after the filter and additional pumping would have been needed to maintain the 1.5 L/min flow.

Table 1. Dissolved organic carbon content after pre-treatment at different flow rates.

	FLOW RATE (L/MIN)				
	Raw	**1**	**1.5**	**2**	**2.5**
Dissolved organic carbon (mg/L)	9.2	0.1	0.1	0.7	1.6

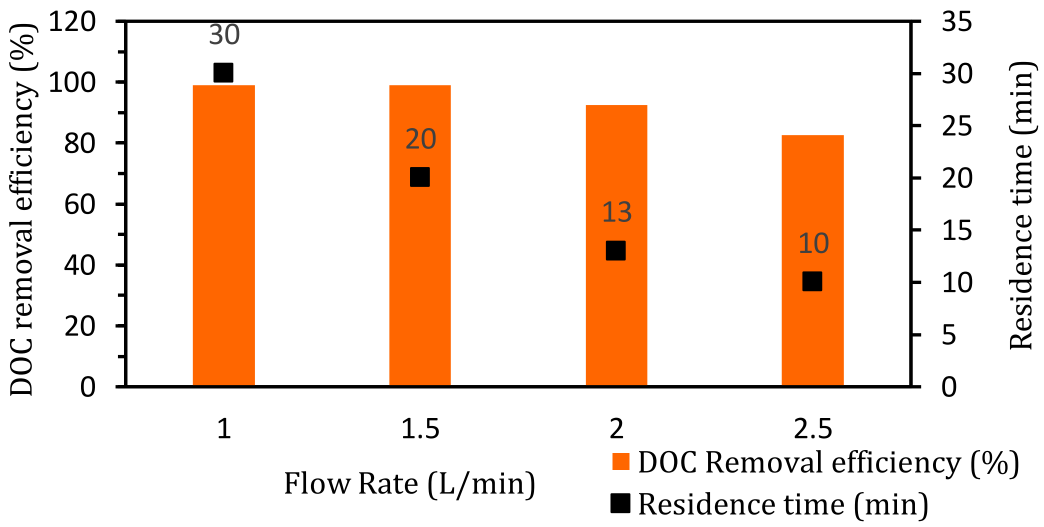


Figure 3. The removal of dissolved organic carbon by granular activated carbon filter at different flow rates.

4.2 Desalination by CDI with removal of DOC at different flow rate

Preliminary trials were performed to establish a suitable flow rate with the GAC column connected as the pre-treatment process. At each flow rate the CDI was operated for 1 h before a sample was drawn. The product was collected over a period of 1 h, from which a sample was taken. The level of total dissolved solids (TDS) was measured using a portable conductivity meter (HACH). The average TDS and the salt removal efficiencies are shown in Figure 4. The salt removal efficiency declined with increase of the flow rate, indicating that the higher resident times within the CDI electrodes will be more effective, resulting in higher desalination. The average product TDS removal was below 500 mg/L at flow rates below 2 L/min. However, considering the lower efficiency of DOC removal at 2 L/min rate an intermediate feed tank was necessary to maintain the flow over 1.5 L/min (20 min residence time). The salt removal efficiencies dropped from 60% to 40% with the increasing flow rate.

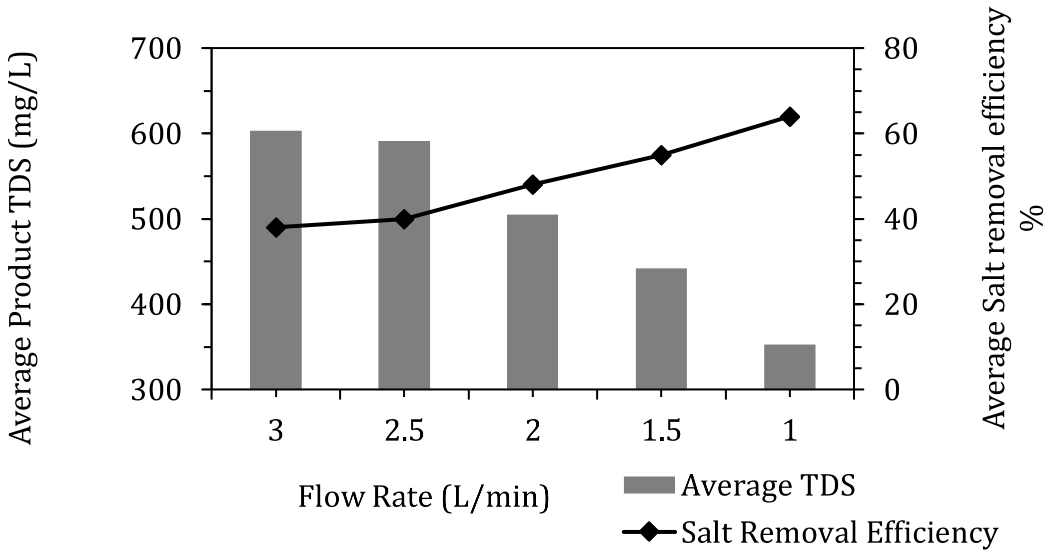


Figure 4. Average product TDS and salt removal efficiencies at different flow rates with removal of DOC by GAC.

The results of water quality analyses are presented in Table 2 and show that reclaimed water has moderate concentrations of the cations, calcium and magnesium and high concentrations of sodium and anions such as bicarbonates, sulphates and chloride. The CDI removed divalent ions such as calcium, magnesium, sulphates and carbonates to about 50% at a flow rate of 2 L/min. The presence of water hardness ions can cause faster electrode saturation necessitating more frequent chemical cleaning. It should be noted that rigorous pre-treatment such as ultrafiltration (UF) was not used for the CDI as is normally done when RO is used. Under the test conditions applied, the CDI contributed to water softening as well as desalination.

The removal of major nutrients is evident while limited fluoride removal occurred at each flow rate (Table 2). Although copper, manganese, zinc and iron were present in relatively low concentrations in the raw water, they appear to have been released from the CDI, which could have been adsorbed in previous application. These ions could also be present in various organo-complexes in Bolivar reclaimed water, which could result from oxidation-reduction reactions within the CDI electrodes. The measured boron concentration in the supply reclaimed water was 0.37 mg/L and this was reduced in concentration to various extents from 80% at 1 L/min rate to 30% at 3 L/min, because of GAC pre-treatment (See Appendix C, Table C.1). The CDI unit did not contribute to boron removal.

Removal data of total organics were obtained from water quality analyses (Table 2) but are not comparable with the earlier results shown in Table 1. The data shown in Table 2 indicates that superfine carbon particles were released from the GAC filter and present in samples collected after the CDI. The fine GAC particles appear to have contributed to the TOC values recorded. As an indirect measure, the DOC content (UV at 254 nm/cm) at each flow rate was determined using UV-Vis spectroscopy and the results (Figure 5) confirmed that compared to raw water there was removal of DOC at each flow rate tested. Removals were consistent as measured at 254 nm/cm.

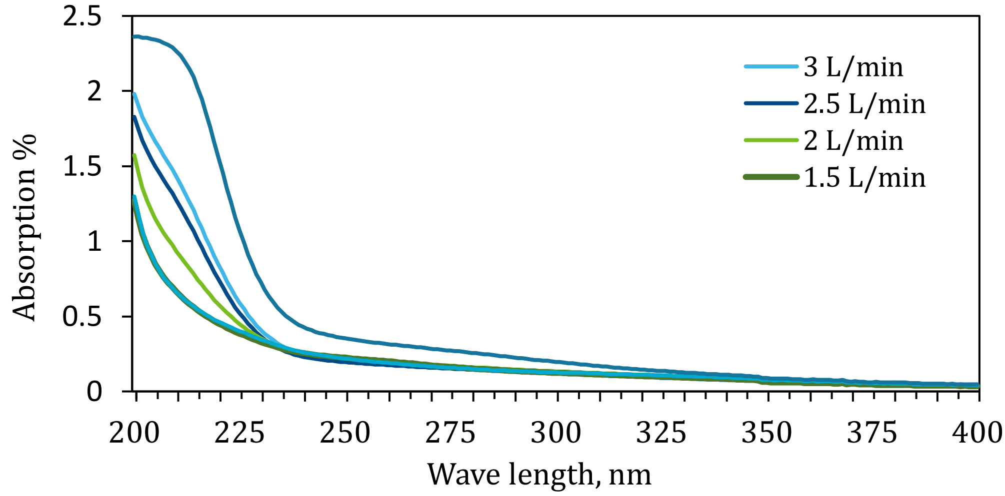


Figure 5. UV-Vis spectra for desalinated water samples at different flow rates.

Table 2. Water quality analysis at different flow rates for Bolivar reclaimed water (with GAC pre-treatment)

PARAMETER	UNIT	FLOW RATE, L/MIN					
		Raw	**1**	**1.5**	**2**	**2.5**	**3**
pH Value	pH Unit	7.61	6.89	5.52	6.37	6.94	7.06
Sodium adsorption ratio		7.92	7.26	6.28	6.76	7.78	7.66
Electrical conductivity @ 25°C	µS/cm	2220	1210	1130	1210	1190	1240
Total dissolved solids @180°C	mg/L	1080	731	729	745	688	721
Total hardness as $CaCO_3$	mg/L	287	146	137	147	107	120
Hydroxide alkalinity as $CaCO_3$	mg/L	<1	<1	<1	<1	<1	<1
Carbonate alkalinity as $CaCO_3$	mg/L	<1	<1	<1	<1	<1	<1
Bicarbonate alkalinity as $CaCO_3$	mg/L	139	120	41	69	84	95
Total Alkalinity as $CaCO_3$	mg/L	139	120	41	69	84	95
Sulphate as SO_4	mg/L	201	116	122	130	98	107
Chloride	mg/L	467	254	257	272	284	285
Calcium	mg/L	49	29	27	26	18	20
Magnesium	mg/L	40	18	17	20	15	17
Sodium	mg/L	308	203	170	188	186	195
Potassium	mg/L	43	21	18	23	23	24
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Copper	mg/L	0.004	0.004	0.037	0.024	0.026	0.027
Manganese	mg/L	0.011	0.03	0.027	0.024	0.014	0.017
Strontium	mg/L	0.374	0.322	0.288	0.259	0.2	0.212

Zinc	mg/L	0.021	5.1	8.46	3.86	1.95	1.61
Boron	mg/L	0.37	<0.05	0.18	0.24	0.24	0.27
Iron	mg/L	<0.05	0.44	0.46	0.22	0.11	0.07
Fluoride	mg/L	0.6	0.6	0.4	0.4	0.4	0.4
Nitrite as N	mg/L	<0.01	<0.01	<0.01	0.01	0.02	0.11
Nitrate as N	mg/L	3.64	<0.01	0.24	0.92	1.73	1.65
Nitrite + nitrate as N	mg/L	3.64	<0.01	0.24	0.93	1.75	1.76
Total phosphorus as P	mg/L	0.06	0.01	0.04	<0.01	<0.01	<0.01
Total organic carbon	mg/L	6.1	31.6	52	36.85	15.2	19.3

From preliminary trials conducted further desalination experiments were performed at a CDI unit flow rate of 1.5 L/min. This was to remove DOC and attain salt removal near optimum for the flow rates investigated.

4.3 The desalination performance over 24 h period with and without GAC pre-treatment

The flow rate was set to 1.5 L/min and the salt removal performance was monitored over a period of 24 h to identify the effectiveness of desalination and the optimum time to conduct chemical cleaning. Experiments were performed with the GAC filter connected, as well as being disconnected, from the CDI process.

Over 24 h of operation with GAC pre-treatment (Figure 6), the average salt removal efficiency dropped from approximately 50% to 20%. In contrast, when the GAC pre-treatment was disconnected the average salt removal performance dropped from approximately 30% to 10% within 11 hours. This clearly shows that DOC and/or other constituents present in the source water and removed by the GAC had a detrimental effect on the performance of this CDI unit. The temperature of the feed water fluctuated significantly under field conditions at Bolivar thus resulting in unstable output TDS, as similarly reported by (Mossad and Zou 2013a, 2012).

In addition to determination of the average salt removal efficiency with GAC, the highest salt removal efficiency was also monitored after the GAC column was disconnected. The highest desalination was recorded at the end of the product cycle, as would be expected, and samples were collected in the last 10 sec of the product cycle. Comparison of the average and highest desalination efficiencies is shown in Figure 7. The highest desalination efficiency remained at approximately 50%, while the average desalination efficiency dropped during the operational period. Output salinities varied from the feed concentration to a lowest level towards the end of the 90 sec product water supply period (of the 150 sec CDI cycle). This observation can be explained in regards to the electrode material quality where, predominantly the porosity of activated carbon leads to slower electrode charging and ion diffusion within the pores. In addition, the any DOC and other constituents not removed by GAC could result in DOC and inorganic constituents occupying these electrode adsorption sites faster, thus reducing the desalination capacity. Table 3 shows that metals and other inorganic constituents were removed as well as organics by the GAC.

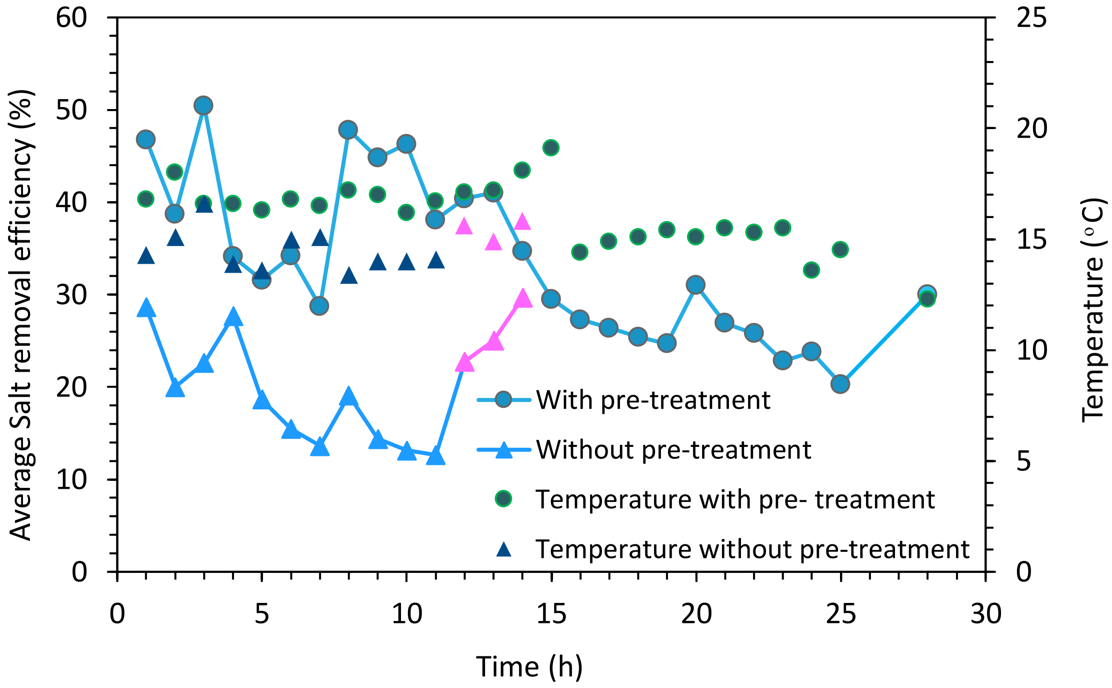


Figure 6. Salt removal performance over 24 hours with and without the pre-treatment. Pink and light blue symbols represent recovery after cleaning.

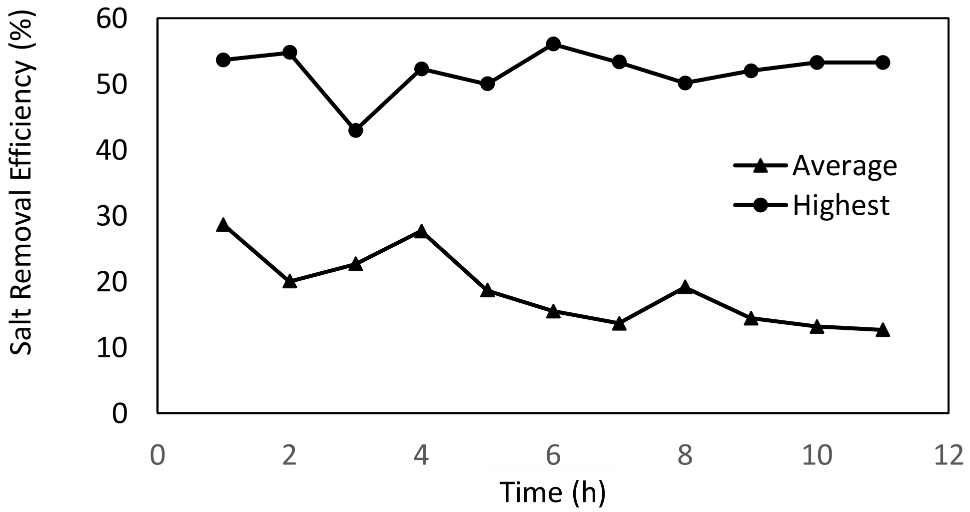


Figure 7. Highest and average salt removal efficiencies of Bolivar water without GAC pre-treatment.

Results of water quality analyses are given in Table 3. In summary:

- Boron was removed at 48% during the first hour by the GAC pre-treatment and efficiency of removal declined over 12 h to no removal being detected. After disconnecting the GAC pre-treatment, boron was not removed by the CDI process.
- Levels of copper, manganese and zinc were higher than in the input water indicating a degree of mobilisation of previously deposited ions.
- Iron, which is a major scalant in CDI operation was removed from previous depositions at 1 L/min rate without further removal at increased flow rates and over the 12 h period. This observation was

similar with and without GAC pre-treatment. Fluoride ions showed a similar behaviour to iron. i.e. at the beginning of the trial previously deposited fluoride ions were removed from the system which subsequently showed no removal by CDI over 12 h, observed both with and without the GAC pre-treatment. The lower pH at 1 L/min could be attributed to citric acid use for cleaning or unknown effects from the use of GAC, in the first hour of operation.

- Mercury levels were below the detection limits during the trials.

Table 3. Water quality analysis for 24 h operation with and without the GAC pre-treatment.

PARAMETER	UNIT	WITH GAC PRE-TREATMENT				WITHOUT GAC PRE-TREATMENT		
		RAW	**1 h**	**12 h**	**24 h**	**RAW**	**2 h**	**11 h**
pH Value	pH Unit	7.36	5.68*	7.01	7.2	7.57	6.48	7.04
Sodium adsorption ratio		7.69	6.23	8.98	8.4	7.66	7.9	8.59
Electrical conductivity @ 25°C	µS/cm	1860	960	1150	1430	1930	1480	1620
Total dissolved solids @180°C	mg/L	1000	608	605	804	1040	846	905
Hydroxide alkalinity as $CaCO_3$	mg/L	<1	<1	<1	<1	<1	<1	<1
Carbonate alkalinity as $CaCO_3$	mg/L	<1	<1	<1	<1	<1	<1	<1
Bicarbonate alkalinity as $CaCO_3$	mg/L	105	44	102	120	121	68	105
Calcium	mg/L	36	18	11	19	36	28	25
Magnesium	mg/L	34	15	12	20	34	24	25
Potassium	mg/L	41	13	23	29	39	29	34
Sodium	mg/L	268	148	181	220	267	236	254
Total alkalinity as $CaCO_3$	mg/L	105	44	102	120	121	68	105
Total hardness as $CaCO_3$	mg/L	230	107	77	130	230	169	165
Copper	mg/L	0.005	0.34	0.06	0.045	0.004	0.254	0.168
Manganese	mg/L	0.006	0.028	0.006	0.008	0.018	0.009	0.005
Strontium	mg/L	0.295	0.183	0.124	0.185	0.321	0.207	0.216
Zinc	mg/L	0.044	6.76	0.898	0.96	0.026	2.24	0.777
Boron	mg/L	0.27	0.14	0.22	0.22	0.28	0.26	0.27
Iron	mg/L	<0.05	0.9	<0.05	<0.05	<0.05	<0.05	<0.05
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Sulphate, SO_4	mg/L	205	105	96	139	203	163	172
Chloride	mg/L	434	226	263	324	431	363	381
Fluoride	mg/L	0.3	0.6	0.3	0.3	0.4	0.4	0.3
Nitrite as N	mg/L	0.02	0.93	0.16	0.36	<0.01	0.02	0.04
Nitrate as N	mg/L	11	0.01	2.71	4.81	8.81	5.96	9.65
Nitrite + nitrate as N	mg/L	11	0.61	2.87	5.17	8.81	5.98	9.69
Total phosphorus as P	mg/L	0.04	0.02	0.01	0.01	0.02	0.01	0.01

** This low pH may be due to the effects of GAC or from citric acid use in cleaning.*

4.4 Chemical cleaning of CDI during reclaimed water desalination

The chemical cleaning was performed manually by rinsing with potable water and chemical reagents that were manually prepared. The trial unit was equipped with an in-line TDS probe but does not have an in-built automatic cleaning capability.

Chemical cleaning was performed after 24 h of desalination with GAC pre-treatment and after 11 h of desalination without GAC pre-treatment. The following cleaning cycle was used after the desalination experiment with the GAC pre-treatment:

- Flushed the CDI with 20 L of potable water at 1.5 L/min flow rate.
- Circulated 20 L of 0.01 mg/L citric acid solution at 1.5 L/min flow rate.
- Flushed with 20 L of potable water at 1.5 L/min flow rate.

The above cleaning cycle restored the desalination efficiency from approximately 10% to 30%. This is indicated in Figure 5 (the point at 25 h). The average TDS of the product was 680 mg/L, after first chemical wash. Then the procedure was repeated with the citric concentration increased to 0.02 mg/L. The increased citric concentration restored the desalination efficiency to ~50%. The above cleaning process removed the inorganic scaling in the CDI.

When the desalination experiment was continued without GAC pre-treatment, the citric acid alone could not restore the performance of CDI. As indicated in Figure 5 (efficiency at 12h) the citric acid rinsing could restore CDI efficiency to only 50% of the initial capacity. Additional washing with 20 L of sodium hydroxide at a concentration of 0.02 mg/L removed the organic fouling in the electrodes (Figure 5, efficiency at 14 h without GAC). It should be noted that the above chemical cleaning processes were successful in restoring the desalination capacities to that at the beginning of the trial. These combinations may however, not be optimum conditions for cleaning. In addition, the long-term effects of the cleaning reagents, citric acid and sodium hydroxide on the electrode materials are unknown and for this to be determined comprehensive laboratory based testing would be needed.

4.5 Water recovery by CDI in the desalination of reclaimed water

When GAC pre-treatment was used, the efficiency of salt removal was approximately 20% at 24 h. However, without pre-treatment only after 11 h, the efficiency declined to ~ 10%. The configuration of the trial CDI unit (discharge of brine for 30 sec and product for 90 sec) converted 30% of the feed to brine. This initial setting was not changeable in this unit. However modern commercial CDI systems have the capacity to alter the durations at which product and brine are produced. Production volumes were also affected by the fluctuations in the feed supply and scaling and fouling of electrodes as also reported by Mossad et al. (2013).

The water recovery from the CDI operation was calculated as the percentage of product to the feed water by the following equation:

$$Water\ recovery = (V_F - V_B - V_C) * 100 / V_F$$

where V_F, V_B and V_C are volumes of feed, brine and chemical cleaning water.

Various measured water volumes during the two trials and the water recovery rates are listed in Table 4. Higher water recovery can be achieved by using effective pre-treatment techniques. The GAC filter was only used as a protective measure for the trial CDI system. The GAC removed dissolved organic compounds and some inorganic constituents. According to available sources, current RO practices in the NAP, include pre-treatment being predominantly performed by ultrafiltration (UF) for RO desalination of reclaimed water. UF can remove particulate and some fractions of organic components (depending on molecular weight) as well as inorganic scaling thus increasing the efficiency of the RO process.

Table 4: Water yields in reclaimed water desalination by CDI

	DURATION	FEED VOLUME	CLEANING WATER VOLUME	BRINE VOLUME	PRODUCT WATER	WATER RECOVERY
	h	**L**	**L**	**L**	**L**	**%**
With GAC pre-treatment	24	1716	100	510	1206	64
Without GAC	11	743	100	203	540	59

The above water recovery estimations do not include the back flushing of the GAC filter. The regeneration of GAC after its saturation could be achieved mainly with back flushing with an alkaline solution which were not experimented in these trials considering the economics and the time limitation. Compared to UF, the regeneration of granulated activated carbon can be inefficient.

4.6 Energy consumption of CDI in desalination of reclaimed water

The power consumption of CDI at different flow rates and over 24 h operations were monitored and recorded every 10 sec. According to the CDI unit configuration, the polarity of the electrodes is reversed three times during the 150 sec cycle (Figure 8). The data recorded showed that the power consumption fluctuated significantly when the electrode potential was reversed at the beginning of the brine and product discharging, thus requiring more electrical current/power. During the desalination period the power consumption quickly dropped to its lowest level. This power fluctuation can be attributed to the electronic architecture of this specific CDI system. The manufacturer specifications suggest that the peak starting current could be as high as 130 A at 1.5 VDC for 2 sec per CDI cell at 1000 ppm TDS. This high current should drop by 50% within the next 10 sec of desalination or regeneration. With this system, these power spikes last a few seconds.

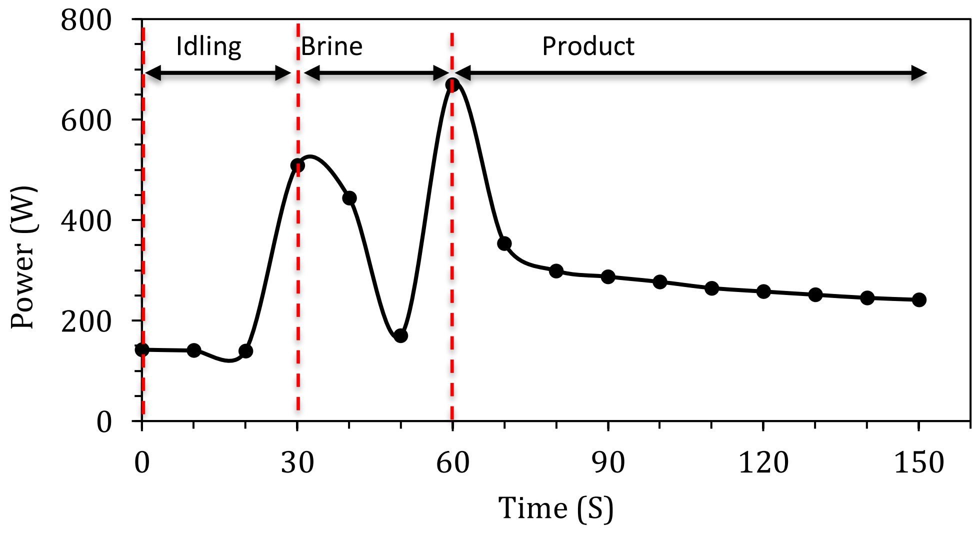


Figure 8. Energy consumption measured during the CDI cycling (Flow rate-1.5 L/min).

The power consumption was recorded over 10 cycles to obtain the energy consumption per kilolitre of product water at each flow rate tested (Figure 9) and over the continued period (Figure 10) with and without GAC pre-treatment. From Figure 9, it can be seen that the energy consumption declined with the increasing flow rate indicating that the higher the salt removal capacity (low flow rates), the higher the energy consumed. The average energy consumption was approximately 3.5 kWh/kL when the GAC filter was in line which increased slightly to approximately 3.8 kWh/kL when the filter was not used. This increase in power consumption can be attributed to the loading of organics and inorganics on and into the electrodes thus needing more current to establish their electrode potential. Over time, the energy consumption was relatively stable.

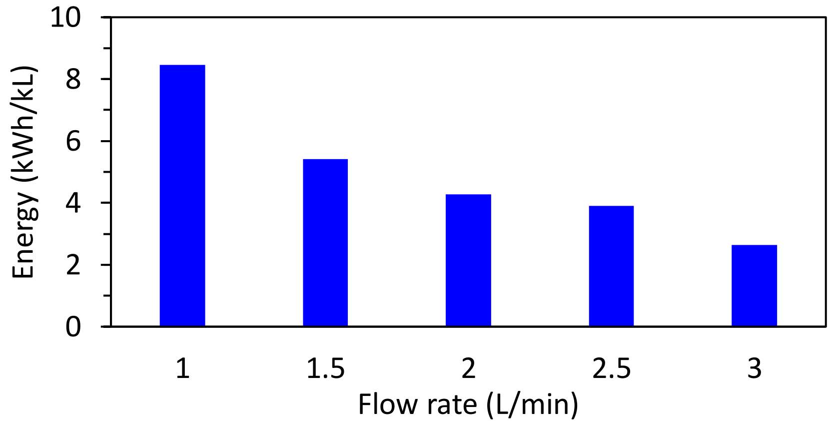


Figure 9. Energy consumption of CDI at various flow rates with GAC pre-treatment.

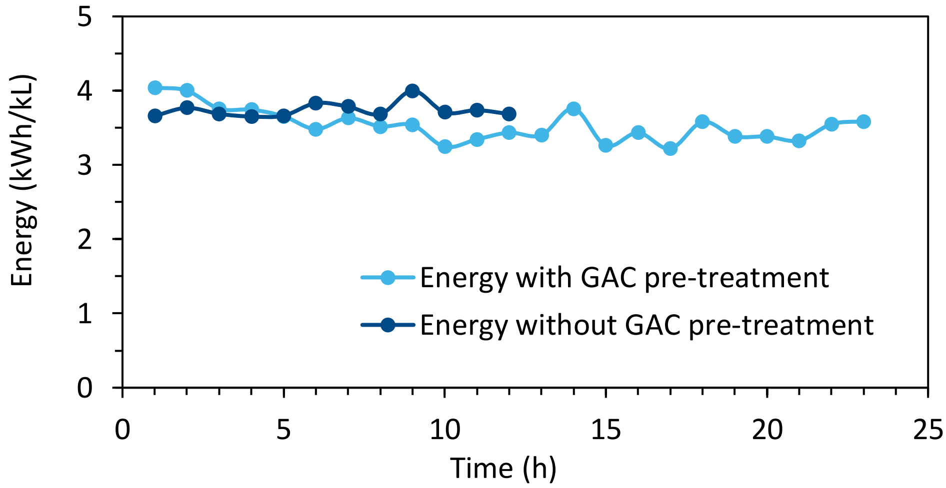


Figure 10. Energy consumption during 24 h operation with and without GAC pre-treatment.

5 Results: desalination of bore water by capacitive deionization

The desalination of bore water by CDI was studied at P'Petual Holdings Pty Ltd located at Buckland Park, South Australia. The bore water TDS was approximately 700-800 mg/L. Initial bore water quality assessment showed that the dissolved organic carbon content was 0.7 mg/L. As a result, the trials were carried out without any pre-treatment for removal of dissolved organic matter. A cartridge filter (10 µm) was used to remove any suspended solids in the feed bore water to the CDI. The CDI feed water was taken from a bore water storage tank which also fed the ultrafiltration plant (RO pre-treatment) and boilers. A centrifugal Davy pump (0.78 kW) was used to supply the feed to the CDI unit as the pressure from the storage tank was inadequate for this.

Bore water desalination tests were conducted immediately after the trials on reclaimed water were completed. The CDI unit was thoroughly cleaned with citric acid followed by sodium hydroxide as performed for the Bolivar trials. In addition, the CDI was flushed with potable water for 1 h and 6 mg/L of chlorine as hypochlorite solution for disinfection of the unit. The CDI and associated equipment were set up inside a P'Petual glasshouse section where temperature is controlled at 25 °C, and where a RO plant is located.

5.1 Desalination performance of CDI at various flow rates of bore water

To identify a suitable flow rate for the CDI unit, preliminary trials were carried out by varying the flow rate between 1 to 3 L/min (Figure 11). The CDI unit was flushed with 10 L of 0.01 mg/L citric solution and 20 L of RO permeate (TDS ~ 20 mg/L) before changing flow rate. The feed flow fluctuated when the flow rate was increased to 3 L/min. The trial was carried out at this flow rate using an intermediate feed tank. The average salt removal efficiency for all flow rates was between 20–30% while the highest salt removal efficiency was over 50%.

The water quality analyses at each flow rate (Table 5) showed similar results to reclaimed water. The water hardness was lower in bore water compared to reclaimed water however, the overall performance was similar to that of reclaimed water without GAC pre-treatment. The major cations and anions were significantly removed. Fe ions were present in low concentrations and were further removed by CDI treatment. Other ions such as boron, phosphorous and fluoride were not removed by CDI.

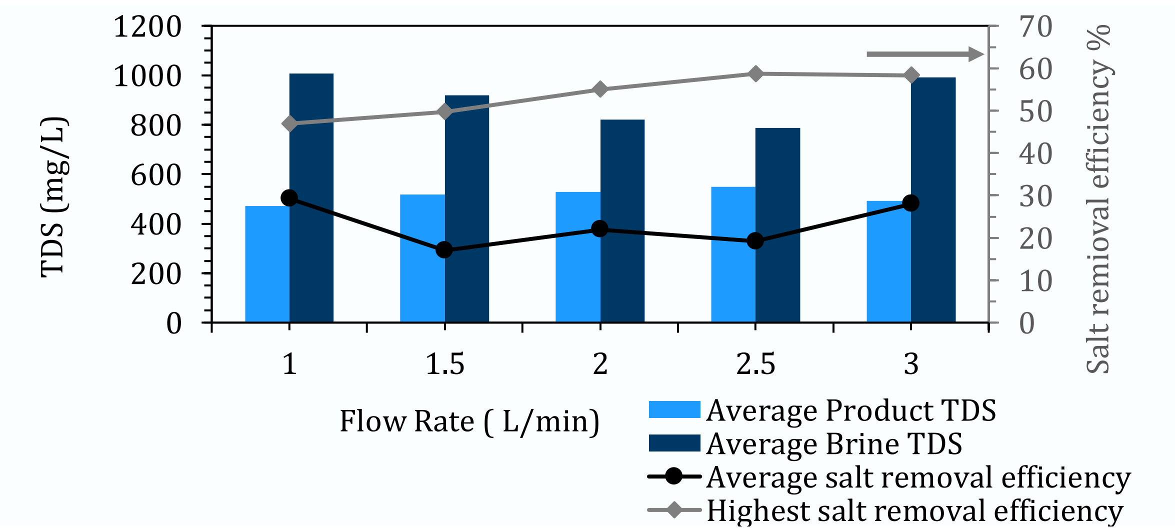


Figure 11. Desalination efficiencies at different flow rates for bore water.

In the trial conducted at P'Petual Holdings it was observed that during the first ~15 min of CDI operation, the TDS of the brine waste was lower than the feed water. This indicates that instead of being rejected during the brine cycle, the salts remained adsorbed / re adsorbed into the electrodes. It is speculated that cleaning of the CDI with citric acid and sodium hydroxide (used after the Bolivar trial to remove organics from the electrodes) may have resulted in increased active electrode area. Alternatively, the cleaning by sodium hydroxide had a detrimental effect on the surface coating of the electrodes that inhibited co-ion adsorption during brine cycle. After 15 min, the brine concentration increased over the feed water, showing electrode regeneration. The flow rate was fixed at 2 L/min for subsequent trials.

Table 5. Water quality analyses of pre- and post-desalinated bore water at different CDI flow rates.

PARAMETER	UNIT	FLOW RATE (L/MIN)					
		Raw	*1*	*1.5*	*2*	*2.5*	*3*
pH	pH Unit	7.88	7.53	7.26	7.28	7.38	7.35
Sodium adsorption ratio		4.28	4.64	4.7	4.67	4.67	4
Electrical conductivity @ 25°C	µS/cm	1370	905	1050	1060	1120	981
Total dissolved solids @180°C	mg/L	769	552	588	685	639	614
Total hardness as $CaCO_3$	mg/L	272	150	185	203	209	210
Hydroxide alkalinity as $CaCO_3$	mg/L	<1	<1	<1	<1	<1	<1
Carbonate alkalinity as $CaCO_3$	mg/L	<1	<1	<1	<1	<1	<1
Bicarbonate alkalinity as $CaCO_3$	mg/L	228	224	190	192	194	194
Total alkalinity as $CaCO_3$	mg/L	228	224	190	192	194	194
Calcium	mg/L	61	24	33	40	44	46
Magnesium	mg/L	29	22	25	25	24	23
Sodium	mg/L	162	131	147	153	155	133
Potassium	mg/L	9	8	8	8	8	7
Chloride	mg/L	266	159	199	224	243	213
Sulphate as SO_4	mg/L	82	31	53	57	53	58
Copper	mg/L	0.014	0.029	0.053	0.031	0.031	0.088
Manganese	mg/L	0.007	0.006	0.007	0.008	0.007	0.007
Strontium	mg/L	0.612	0.205	0.256	0.319	0.362	0.398
Zinc	mg/L	0.048	2.06	1.4	1.02	0.604	0.65
Boron	mg/L	0.14	0.19	0.14	0.15	0.14	0.15
Iron	mg/L	0.22	0.07	0.07	0.06	0.06	0.11
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fluoride	mg/L	0.4	0.3	0.4	0.4	0.3	0.3
Total phosphorus as P	mg/L	0.03	0.02	0.06	0.06	0.05	0.05
Turbidity	NTU	1.9					

5.2 The desalination performance over 24 h period for bore water

Desalination of bore water was continuously tested for a period of 24 h, at 2 L/min flow rate. Over a 24 h test period (Figure 12), the highest salt removal efficiency remained stable approximately 57% for 8 h and then declined to approximately 50%. The average salt removal efficiency dropped from 35% in the first hour to between 15–20% for the remaining period. The output TDS was relatively stable compared to that obtained for reclaimed water given that the trials were conducted indoor (inside a glass house) with continuous temperature control. Over the 24 h period, CDI became less efficient in removing various ions (Table 6). The desalination capacity of the CDI unit for bore water was lower compared to that of reclaimed water. From calculation of constituent balance, it was evident that there was salt ion accumulation in the electrodes over time.

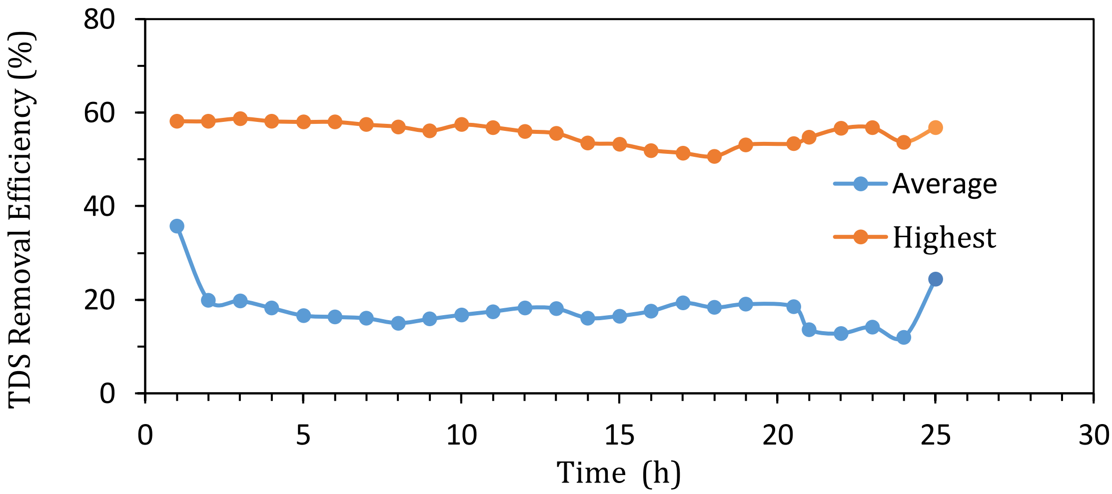


Figure 12. Salt removal efficiency over a 24 h period for the bore water tested.

Table 6. Water quality analysis at over 24 h period for groundwater.

PARAMETER	UNIT	RAW	1 H	12H	24H
pH Value	pH Unit	7.82	7.02	7.7	7.74
Sodium adsorption ratio		4.37	4.18	4.73	4.6
Electrical Conductivity @ 25°C	µS/cm	1390	899	1130	1180
Total Dissolved Solids @180Â°C	mg/L	741	582	638	631
Total Hardness as $CaCO_3$	mg/L	282	177	198	195
Hydroxide Alkalinity as $CaCO_3$	mg/L	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	229	124	198	214
Total Alkalinity as $CaCO_3$	mg/L	229	124	198	214
Calcium	mg/L	62	38	43	42
Magnesium	mg/L	31	20	22	22
Sodium	mg/L	169	128	153	148
Potassium	mg/L	10	6	8	8
Chloride	mg/L	275	181	220	232
Sulphate as SO_4	mg/L	90	47	58	57
Copper	mg/L	0.002	0.225	0.003	0.005
Manganese	mg/L	0.007	0.006	0.005	0.006
Strontium	mg/L	0.595	0.328	0.432	0.444
Zinc	mg/L	0.029	1.44	0.455	0.844

Boron	mg/L	0.13	0.13	0.13	0.13
Iron	mg/L	0.22	0.16	<0.05	<0.05
Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
Fluoride	mg/L	0.3	0.3	0.3	0.4
Total Phosphorus as P	mg/L	0.04	0.05	0.08	0.04

5.3 Chemical cleaning of the CDI after desalination of bore water for 24 h

At the end of 24 h period, the CDI unit was flushed with 25 L of RO water followed by 20 L of 0.01 mg/l citric acid and 50 L of RO water. The desalination process was repeated for 1 h to identify the effectiveness of the cleaning. At the end of 1 h, the average product salinity was 516 mg/L while the lowest salinity of the product was 215 mg/L corresponding to average and highest desalination efficiencies of 24% and 57% respectively.

5.4 Water recovery during bore water desalination by CDI

Various measured water volumes during the desalination of bore water over the 24 h period at 2 L/min flow rate and the water recovery rates are detailed in Table 7.

Table 7. Water recovery from the desalination of bore water.

	DURATION	FEED VOLUME	CLEANING WATER VOLUME	BRINE VOLUME	PRODUCT WATER VOLUME	WATER RECOVERY
	HR	**L**	**L**	**L**	**L**	**%**
Bore water without pre- treatment	24	2152	95	517	1635	72

The desalination of groundwater by CDI has simpler chemical cleaning need compared with reclaimed water and with higher water recovery at 72%.

5.5 Energy consumption of CDI in desalination of bore water

The power consumption of the CDI unit during the desalination of bore water at different flow rates over 24 h period are shown in Figures 13 and 14. Similar to reclaimed water desalination, the energy consumption declined with the increasing flow rate. The average energy consumption at 2 L/min flow rate was approximately 3.5 kWh/kL which is comparable to the energy consumption when reclaimed water is desalinated with pre-treatment with GAC filter. The measured data do not include the energy consumption of the Davy pump (power rating 0.78 kW) that was used to feed the CDI unit.

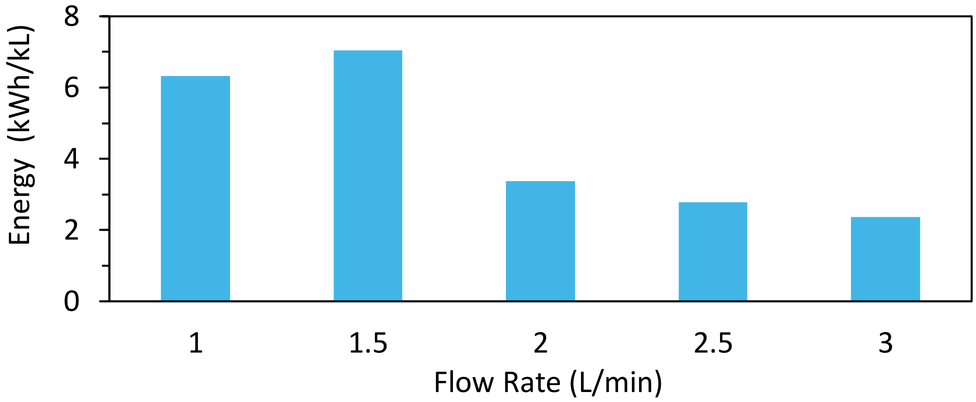


Figure 13. Energy consumption at different flow rates for bore water desaliantion.

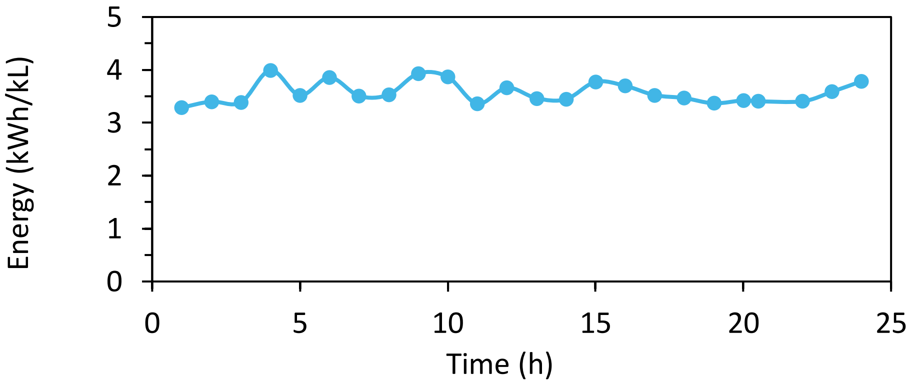


Figure 14. Energy consumption over 24 h period for desalination of bore water.

6 Comparison of CDI to current desalination practices in the NAP region

Current use of desalination in the NAP region by horticultural enterprises is based on RO plants. In order to compare costs of CDI to RO, two Australian installers of RO in the NAP (Integra (Vyner 2017) and Fresh Water Systems (Nicholas 2017)) were consulted. Integra has installed 15–20 RO plants in the last two years including a 100,000 L/day plant for reclaimed water desalination. Fresh Water Systems has also installed several RO plants and the largest being 1.1 million L/day plant and 2 x 500,000 L/day plants installed in the NAP. CDI prices were obtained from AQUA, USA (Atlus 2017).

The daily water use by hydroponic farms in the NAP generally varies from 5,000–9,000 L/h. Most common RO installations are with capacity to approximately 200,000 L/day. However, larger installations to capacities of 400,000 L/day or more are possible (source Integra; Fresh Water Systems).

Most RO plants in the NAP use brackish water with salinities of approximately 1500–2000 mg/L. Fresh Water Systems has installed one RO plant in Dublin where feed salinity is 8000 mg/L.

6.1 Pre-treatment processes

The performance of RO can be limited by components such as organic carbon, iron, manganese, silica and microbial content. Pre-treatment processes are accordingly applied.

For brackish groundwater, standard pre-treatment for small scale plants could include back washable media filter, anti-scaling dosing and 5 and 1 micron filters.

For Bolivar reclaimed water, ultrafiltration and microfiltration have been recommended as pre-treatment by Integra and Fresh Water Systems. Microfiltration treatment consists of variable back wash, Automatic Chemical Enhanced Backwash (CEB) and manual Cleaning in Place (CIP). Ultrafiltration membranes need air scouring and back washing every 30 minutes to maintain membrane performance. Chemical cleaning is desirable every three months, however the automatic CEB processes can be initiated daily if required.

Performance of CDI plants is also affected by the presence of inorganic ions and organic carbon. However, in contrast to RO, CDI is known to have lesser microbial fouling and silica scaling issues (Mossad and Zou 2013b). As a result, pre-treatment for CDI should mainly focus on dissolved organic carbon and suspended solids removals. Most CDI installations are sold with automatic TDS monitoring and chemical cleaning, although the CDI unit used did not possess automatic cleaning capacity.

6.2 Desalination and pre-treatment costs

Estimations of costs provided by Integra was based on their common installations. Fresh Water Systems included prices for feed salinity at 5000 mg/L. Estimate costs provided by AQUA varied for different source water salinities (Appendix D). A cost comparison is given in Table 8.

Table 8. Comparison of capital costs of CDI with current conventional desalination and pre-treatment technologies applied in the NAP.

	DESALINSATION TECHNOLOGY			
DESALINATION/ PRE-TREATMENT	REVERSE OSMOSIS	MICRO-FILTRATION	ULTRA-FILTRATION	CAPACITATIVE DE-IONISATION
Small scale systems				
BW 5,000 L/day	$ 10–12 K[a]	$ 8 K[a] (RW)		$ 5 K[c] (~6.6K AUD)
BW 10,000 L/day	$ 12–15 K[a]	$ 10 K[a] (RW)		$ 6–12 K[c] (~8-16 K AUD)
BW 20,000 L/day				$ 8–16 K[c] (~10.5-21K AUD)
Medium scale systems				
BW 100,000 L/day	$ 70 K[b]		$ 80 K[b]	
BW 120,000 L/day	$ 76 K[a]		$ 29 K[a]	$ 39 K[c] (~51K AUD)
BW 200,000 L/day	$ 110 K[b]		$ 150 K[b]	$ 50 K[c] (~66K AUD)
BW 240,000 L/day	$ 99 K[a]		$ 43 K[a]	$ 78 K[c] (~103 K AUD)
Large scale systems				
BW 400,000 L/day	$ 150 K[b]		$ 210 K[b]	

BW- Brackish Water, RW- Reclaimed Water.

[a] Fresh water Systems AUD$, [b] Integra water systems AUD$, [c] AQUA EWP US$ (AUD$),

In addition to the above equipment costs, installation costs of RO in a container could be in the order of $12,000 per unit. The stated costs of CDI installations provided by AQUA are generally lower or similar, however the performance can vary depending on the feed water quality. For instance, a commercial CDI system that can desalinate feed water salinity of 3000 mg/L at 3.6 kL/day costs around $3,000. 12 modules of similar capacity could come at an individual cost of $1,750/module. Higher production capacities are achieved by adding several modules in parallel and the price is adjusted according to the number of single systems. Additional costs will be incurred if microfiltration or ultrafiltration is used as pre-treatment.

Pre-treatment to remove organic fouling and inorganic scaling is likely to be required for any CDI treatment of reclaimed water. Microfiltration and ultrafiltration might be used as pre-treatment technologies, and cost estimates are from $8,000 to $29,000 for small (5-10 kL/day) to medium scale (100 kL/day) operations (Nicholas 2017).

Comprehensive details of the factors to be considered in the assessment of groundwater desalination costs can be found in Barron et al. (2015).

7 Challenges in the application of CDI in the NAP

The desalination trials conducted at Bolivar WWTP and P'Petual Holdings Pty Ltd using the trial CDI unit for reclaimed water and bore water indicated that CDI technology could be applied to lower salinity, by at least 30%. This salt removal performance is significantly below that detailed by the instrument's manufacturer and is likely to have resulted from the current system being an early model that had been extensively used for research and development. The study showed that compared to reclaimed water, application of CDI to groundwater desalination provided higher water recovery rates (64% with pre-treatment of reclaimed water and 72% for bore water without pre-treatment).

These data need to be considered in context of currently available CDI technologies designed for various uses (commercial, industry and horticulture) and manufacturer claimed performances and applications. CDI technology suitability for the horticulture industry requires assessment of capital, operation and maintenance costs, CDI technology reliability, manufacturer and supplier on-going support, source water quality, target water quality, recycling water capacity with applied desalination technology and comparative economics to other desalination technologies.

Currently RO treatment of source (feed) waters (reclaimed and bore) is performed to provide high quality waters for use by the hydroponics industry of the NAP. The supply water is further used to carefully manage fertiliser and pesticide applications. It appears that desalination performance of CDI technologies would need to match those of RO performances. Where bore water and reclaimed water TDS levels are sufficiently low to enable a single pass CDI treatment to achieve a target TDS and achieve required flow/supply rates, then potentially CDI technology would be applicable.

In this study, no evidence was found that CDI treatment is able to remove boron, while removal by RO can be expected. Hence, consideration of technology suitability should include assessment of other water quality parameters beyond TDS, and needs to account for potential contaminants that may be present (continually or sporadically) in source waters, and whether the technology can reliably remove those contaminants if and when present.

New and modern CDI technology would need to be trialled in order to determine practical desalination performances under site specific conditions. If consistent high efficiency (e.g. 85% or more) could be demonstrated by CDI technology for bore water of about 700-800 mg/L then a single pass CDI treatment is likely to be only needed (achieving a target TDS of <100 mg/L, as with a single pass RO) for the hydroponics industry of the NAP. For this determination, consultation with major CDI companies such as Voltea BV and Enpar Technologies is suggested. Voltea BV have undertaken development of CDI technology (CapDI©, e.g. in the Fource Project) for agricultural use (where the source water is brackish shallow groundwater and treated water is used for soil based and green house horticulture). Such technology might be suitable for treatment of reclaimed and brackish bore waters for soil based green/glass house and hydroponics horticulture in the NAP.

From this project a number of factors were identified that influence CDI performance. These include:

- Temperature dependence of the CDI output quality - the two trial sites, the Bolivar DAFF Plant and P'Petual Holdings provided two different test environments for the CDI unit. One key observation was that the output water quality was dependant on the temperature at which the CDI was operated. During the trial at Bolivar DAFF Plant the feed water temperature varied from 10 °C to 28 °C, and the output salinity fluctuated. In contrast at P'Petual, the environment was highly controlled and consequently the output TDS was relatively stable. While the trial CDI unit used is designed to operate between 20–50 °C, it is recommended for that unit that the application environment be adequately controlled for consistent CDI efficiency.
- The need for effective pre-treatment - like RO, reliable and effective pre-treatment technologies may be needed for the desalination of reclaimed water and bore water, based on the specified source/feed water quality tolerances of that technology. For example, the tolerances of the CDI CapDI© Voltea BV includes turbidity <4 NTU (otherwise pre-filtration such as sand/anthracite, micro or ultra- filtration would be needed), TOC <15 mg/L (otherwise GAC or ultrafiltration-nanofiltration would be needed). Without adequate pre-treatment the desalination capacity of CDI can be affected requiring frequent chemical cleaning and consuming higher energy (than specified by manufacturer). If not regularly cleaned, scaling by calcium, magnesium and iron and fouling by dissolved organic carbon (DOC) could cause irreversible damage to CDI electrodes. Although microbial fouling is limited in CDI, downstream disinfection processes such as Ultraviolet (UV) treatment and/or chlorination may be required to ensure water quality.
- Water supply volumes by CDI systems and low feed salinities - considering horticultural enterprises where the environmental conditions are highly controlled, the output water quality and reliability of supply are of paramount importance. It appears that CDI systems that are currently available in the local market have limited net production supply capacities and work effectively mostly at low feed salinity levels. To achieve production volumes as high as 100 kL/day and treat higher feed salinities, a number of CDI units may need to be installed. Some systems are apparently commercially available that might meet the treated water supply rates as used in the NAP of 5 to 9 kL/hr in hydroponics industries. Voltea BV supply a CDI module IS 48 3 phase 30kW that has a net produced flow of 4.3 to 20 kL/hr; smaller modules such as the IS 24 and IS 36 might also be suitable. Another supplier of CDI technology, Idropan Australia indicated medium sized units can be custom-built. Currently available large CDI systems are less commercially developed than RO technology, though these may rapidly establish commercially in the foreseeable future. It appears that at present, the more commercially available CDI units are small-scale (of several thousand litres /day net production).
- Energy fluctuations over manufacturer specified levels - in this study, the trial CDI unit had higher energy use than of specifications of marketed small-scale CDI units. The recorded level of around 3.5 kWh/kL found in this study is comparable to that of RO. At the time of this study, marketed CDI systems were specified by manufacturers to use much less energy (e.g. AQUA EWP units are rated ~ 0.3 kWh/m^3). The higher energy consumption found may be due the applied CDI's power distribution system and cell arrangement design. Another reason may be due to difference between the applied feed water salinity and the salinity level that a particular system is originally rated for. While higher feed TDS requires higher energy, using a lower TDS rated system to treat higher salinities may lead to significantly greater energy use than expected. This would be particularly so if source waters had salinities requiring in series CDI models to be used. Thus the selection of a CDI system for different feed salinities, should be based on fit-for-purpose use and verified not only on product water quality being attained but also on actual energy use.
- Validation of information on CDI performance and costs from various suppliers - one of the challenging aspects of the current status of CDI as a desalination technology is that there are few readily accessible reports of on-going successful operation of existing installations. From available information, it appears that CDI applications are generally of small scale units e.g. as supplied by Idropan, or are custom-built

commercial systems (e.g. ENPAR, Canada). Voltea BV offers comparatively large-scale CDI modules. Where units are custom-built, the costs of such installations also could be variable, depending on water supply requirements and source water quality. Information on the performances of such systems may not be readily available and assessment could be made through pilot trials under the existing field conditions. Hence, potential applications in the NAP regions and elsewhere should be following detailed pilot scale or demonstration testing before purchase in order to validate performance expectation of potential buyers.

- Limited commercial establishment of CDI Technology currently - under the current market status in Australia, only a few companies supply CDI systems at commercial/industrial scale, leaving potential customers with limitation in choice. In the NAP, marketing of CDI technology through local irrigation equipment suppliers appears to have been very limited. i.e. for small scale units with no know sales, based on personal communication with irrigation equipment suppliers. Further concern includes the adequacy of CDI expertise locally based on unknown application currently and reliability of any after sales services.

Considering the above issues related to CDI, it appears that the technology could be feasible but currently, its commercial establishment is very limited in South Australia. Presently, more evident marketing of CDI units is for the sale of small-scale modules with low net product supply capacities. Larger scale CDI is commercially available by some global based companies, and any consideration for such application on the NAP should be in consultation with companies that manufacture and supply that scale technology. It is strongly recommended that pilot scale testing be undertaken to establish CDI suitability to any horticulture industry, prior to any purchase and ongoing technical support be carefully considered.

8 Governance of desalination

Desalination operation and associated wastewater management in the NAP are governed by the EPA and local councils. While there is potential for both centralised and decentralised water desalination in the NAP, the current report addresses the governance of decentralised applications. Desalination approval and wastewater management operation are addressed within the South Australian Environment Protection Act (1999), Environment Protection (Water Quality) Policy (2015) and Environment Protection Regulations (2009). General duty for the protection of the environment is one of the main aspects of the legislation, which states that:

> *"A person must not undertake an activity that pollutes, or might pollute, the environment unless the person takes all reasonable and practicable measures to prevent or minimise any resulting environmental harm"* (Environment Protection Regulations 2009).

Desalination is a prescribed activity of environmental significance as per Schedule 1 of the Environment Protection Act (1999).

8.1 EPA regulatory requirements for installation of RO/desalination plants

8.1.1 LICENSING OF RO OPERATIONS

In-land desalination (RO) plants and brine disposals are required to be licensed by the EPA based on desalinated water, brine wastewater production and resource efficiency (Section 2.2). In the NAP region there are currently two EPA licenced RO users, both from the hydroponics industry. In principle, licences are issued after the development approvals from the South Australian Department of Planning Transport and Infrastructure and/or relevant councils. The licences are costed based on risk minimisation to the receiving environment as the key criterion. The amount of licence fees payable for a licence for a desalination plant are set in the Environment Protection Regulations 2009 and are split into administrative fees, environment management fees (EMF) and resource efficiency fees. The prices payable can vary from a few to many thousands of dollars. Guidelines and requirements for wastewater management including saline wastewater from desalination are provided by SA EPA. Even when no licence is required, the general environmental duty applies in addition to offence provisions in the Environment Protection (Water Quality) Policy 2015.

8.1.1 BRINE DISPOSAL AND MANAGEMENT

According to EPA sources (Jenkins 2017), non-licenced (small-scale) desalination plants that produce brine discharges are subject to the 'General Environmental Duty' provision in the *Environment Protection Act 1993* and Environment Protection (Water Quality) Policy 2015. In effect this means small-scale desalination plant discharge is considered to be wastewater which should be managed in accordance with the "waste management hierarchy" so as to prevent or minimise any environmental harm that may occur. The question of what constitutes reasonable and practicable application of the waste management hierarchy is difficult to define *a priori* because it requires an assessment of site-specific factors. As a broad generalisation, wastewater would often be managed via the appropriate design and application of a wastewater lagoon, for which there is an EPA guideline. The EPA can also provide case by case advice regarding proposals that include non-licensed wastewater management. All large-scale desalination license applications (or development applications referred to EPA for assessment) are considered on a case by case basis. For inland operation (not discharging to the marine environment), evaporation lagoon/pond with HDPE lining is the preferred option for brine wastewater management (see Wastewater Guidelines, Wastewater Lagoon Construction Nov 2014, EPA509/14). However other options can be considered and those that meet environment protection requirements can be approved. There is potential for further improvement in brine management methods and the EPA is open to consideration of innovative, better brine management options.

8.1.2 POTENTIAL ENVIRONMENTAL AND SOCIAL ISSUES RELATED TO BRINE HANDLING

While the impact of brine discharges on various receiving environments is well documented (Miller et al. 2015), the major concerns for the NAP region will be assessment of the impacts of brine sourced from desalination of reclaimed water and bore water. From one EPA viewpoint (Jenkins 2017), nitrate addition to the soil profile through primary industry activities (via fertiliser application and/or irrigation with treated wastewater) has potential to cause more environmental concern. In that context, any further horticulture development in the NAP and nearby areas requires careful planning and management to ensure the principles of ecological sustainable development are achieved. Considerations should include:

- Release of hazardous compounds from reclaimed water - when reclaimed water is desalinated, in addition to concentrated salt, brine might also contain other contaminants such as Endocrine Disrupting Chemicals (EDC), Pharmaceuticals and Personal Care Product Compounds (PCP) and Synthetic pollutants (Van Leeuwen et al. 2012). The fate of these additional compounds in the receiving environment may be of concern. In this regard containment of such chemicals in evaporation basins is preferred compared to discharge to the sea which already is known to have detrimental impacts on marine eco systems where the fate of these pollutants are unknown.
- Unregulated discharges due to limited control and monitoring of small scale operations - since the licencing threshold is at 200 kL/day process volumes (with wastewater production exceeding 2 ML/year), smaller scale operations and brine discharges are not required to be licenced through a legal framework. Further there is no general inspection regime for unlicensed operators. Thus, it can be expected that a localised increase in the number of smaller operations has potential to cause a significant level of environmental impact.
- Perception of a language barrier in communicating legislation and guideline information on desalination operations to farmers of various ethnic backgrounds. However, this may now be less significant with second and third generations of original refugee/immigrant farming communities being born and educated in Australia.

8.2 Recommendations for governance of desalination

Assessment of the licensing requirements for RO desalination plants and waste discharge management is focused on environmental risk minimisation and achieving practical procedures for brine waste management. Accordingly, instead of a decentralised approach, a centralised desalination plant might be a more environmentally sound and sustainable (for horticulture and agriculture) approach, assuming brine wastewaters were suitably managed by advanced procedures. If small-scale desalination wastewater discharges can be managed effectively by use of individual decentralised evaporation lagoons (that do not overflow or leak significantly) then that may be an alternative to the centralised system that results controlled marine discharge. A decentralised small-scale system would not be subject to EPA licenced regulation and control but would require individual operators to be compliant with the 'General Environmental Duty' provisions in the *Environment Protection Act* 1999. This introduces potential for mismanagement that is not subject to systematic control which can lead to cumulative degradation of water quality and soils.

It should be noted that the NAP hydroponics industry and expansion of that industry along the northern corridor is highly likely to expect to use RO treated water with very low TDS levels. This is for high quality water use and water constituent (e.g. nutrients) control needed by that industry. A centralised RO operation that supplies reclaimed water of lower salinity (e.g. 600 mg/L TDS) than ambient salinity by blending with RO appears unlikely to meet the needs of advanced hydroponics industries based on current practices. These would require further RO treatment of that reclaimed water and also for bore waters the industries has access to. Some soil-based greenhouse horticulture industries in the NAP use bore water at ~ 700 mg/L TDS.

Under the current legislative framework, unlicensed smaller scale RO operations (<200kL/d) and brine discharges in the NAP are of concern, presently and in the future. With the EPA being open to consider new proposals for future guidelines and regulations, the following recommendations are suggested to support the governance of desalination more broadly in NAP:

- Improved information of applications of desalination technologies and brine wastewater management in the NAP - it is suggested that the EPA along with local councils pursue the development of licensing and/or reporting of desalination operations and brine wastewater management to be practical and cost minimal for a wide production scale range of desalination technology users. This to facilitate encouragement of provision of information from the horticulture industry on desalination use and brine wastewater management adopted. Detailed information could be made available on the licensing and reporting processes through fact sheets, discussion forums, and educational programs. e.g. in collaboration with HortEx Alliance, Virginia.
- Common evaporation lagoons for clustered smaller scale (<200 kL/d) desalination plants - for desalination operations of less than 200 kL/day it is suggested that consideration be given on feasibility assessment of installation of networked evaporation lagoons) for localised, precinct hydroponic farms (such lagoons may need to be compliant with the EPA wastewater lagoon construction guideline). These farms providing proportional payments for establishment, use and maintenance of these evaporation lagoons. The ownership may be assigned to a group of farmers, a local council or to state government jurisdiction. Mapping of the distribution of small and medium scale desalination plants in the NAP is suggested to enable identification of suitable locations for such lagoons. Economic feasibility of such systems would need to include on-going pumping costs incurred by the horticulture industry.

9 Conclusions and further recommendations

This study provided a preliminary assessment of CDI technology as a potential desalination option for horticulture industries of the NAP based on public available information (internet sources), direct communication with companies supplying CDI technologies, horticulture industries of the NAP and local irrigation supply companies. The study also undertook an investigation of CDI for treatment of Bolivar reclaimed water and bore water using a small-scale desalination unit that was available. The trial CDI unit used for the study has been owned by UniSA since 2008 and used for research and development purposes.

The high-quality water used by the hydroponics industry of the NAP currently is through RO treatment, with at least one major industry using water with less than 100 mg/L TDS. Assuming this is needed more broadly for the hydroponics industry, then CDI technology would also need to supply water with that level of TDS. With the trial CDI unit applied in this study, this TDS level was not achievable in a single treatment pass. Any implementation of CDI technology at a horticulture/agriculture scale should be after consideration of site-specific requirements and appropriate investigations (pilot scale trials) have been conducted to ensure that the technology will achieve the required water quality. Further, water quality assessment and suitability should be extended to include constituents that are not removed by CDI technology but are removed by RO. Hence, the removal of TDS is only one key water quality parameter for consideration and other source water constituents need to be carefully considered in terms of their tolerances and impacts on particular horticulture crops (perceived and/or real).

Expansion in RO operations of less than 200 kL/d process water and associated brine discharges may become of concern for the environments of the NAP and the Northern Corridor, based on brine waste considerations. It is suggested that state government and local governments of the NAP provide advice regarding best practices for brine handling and treatment, as well as support research for improved brine management technologies and systems. Alternative brine management technology options such as by ultra-high TDS concentration as offered by Atlantis Technologies through their RDI© is suggested for consideration and evaluation.

References

Atlus B (2017) Photos of Aqua EWP unit from UNISA. Wimalasiri, Y. (ed), AQUA, USA.

Barron O, Ali R, Hodgson G, Smith D, Qureshi E, McFarlane D, Campos E and Zarzo D (2015) Feasibility assessment of desalination application in Australian traditional agriculture. *Desalination* 364: 33-45.

Burn S, Hoang, M, Zarzo D, Olewniak F, Campos E, Bolto B and Barron O (2015) Desalination techniques — A review of the opportunities for desalination in agriculture. *Desalination* 364: 2-16.

Goyder Institute for Water Research (2016) *Northern Adelaide Plains Water Stocktake Technical Report.* Goyder Institute for Water Research, Adelaide, South Australia.

Jenkins C (2017) EPA Discussions. Wimalasiri, Y. (ed), Environment Protection Authority, Adelaide.

Miller S, Shemer H and Semiat R (2015) Energy and environmental issues in desalination. *Desalination* 366: 2-8.

Mossad M, Zhang W and Zou L (2013) Using capacitive deionisation for inland brackish groundwater desalination in a remote location. *Desalination* 308: 154-160.

Mossad M and Zou L (2013a) Evaluation of the salt removal efficiency of capacitive deionisation: Kinetics, isotherms and thermodynamics. *Chemical Engineering Journal* 223(0): 704-713.

Mossad M and Zou L (2013b) Study of fouling and scaling in capacitive deionisation by using dissolved organic and inorganic salts. *Journal of Hazardous Materials* 244–245: 387-393.

Mossad M and Zou L (2012) A study of the capacitive deionisation performance under various operational conditions. *Journal of Hazardous Materials* 213–214(0): 491-497.

Nicholas J (2017) RO Information. Wimalasiri, Y. (ed), Fresh Water Systems, Adelaide.

PIRSA (2016) Northern Adelaide Horticulture Production 2020 Growth Scenario, PIRSA Scorecard team, 2016, cited on http://www.pir.sa.gov.au/major_programs/northern_adelaide_plains_agribusiness_initiative

Van Leeuwen J, Kulkani V and Zwpf F (2012) *Impact of Recycled Water Reuse on Natural Resources Health.* Prepared for the Adelaide and Mount Lofty Ranges NRM Board.

Vyner W (2017) Reverse Osmosis Information. Wimalsairi, Y. (ed), Integra, Adeliade.

Watt E, Peat V and Barnett S (2014) *Estimation of groundwater resource capacity and acceptable extraction limits for the Adelaide Plains Water Allocation Plan.* Department for Environment, Water and Natural Resources, Technical note 2014/06.

Appendix A - CDI technology suppliers

Company name	Technology
Aqua EWP, USA	Aqua EWP Electronic Water Purifier systems
Atlantis Technologies, USA	Radial Deionizing super capacitor technology platform (RDITM)
Enpar Technologies, Canada	Electro-static deionization (ESD)
Voltea BV, Netherlands	CapDI technology
Idropan Dell'Orto Depuratori S. R. L., Italy Idropan Australia	Plimmer

Appendix B - desalination results analysis

Analyses of reclaimed water

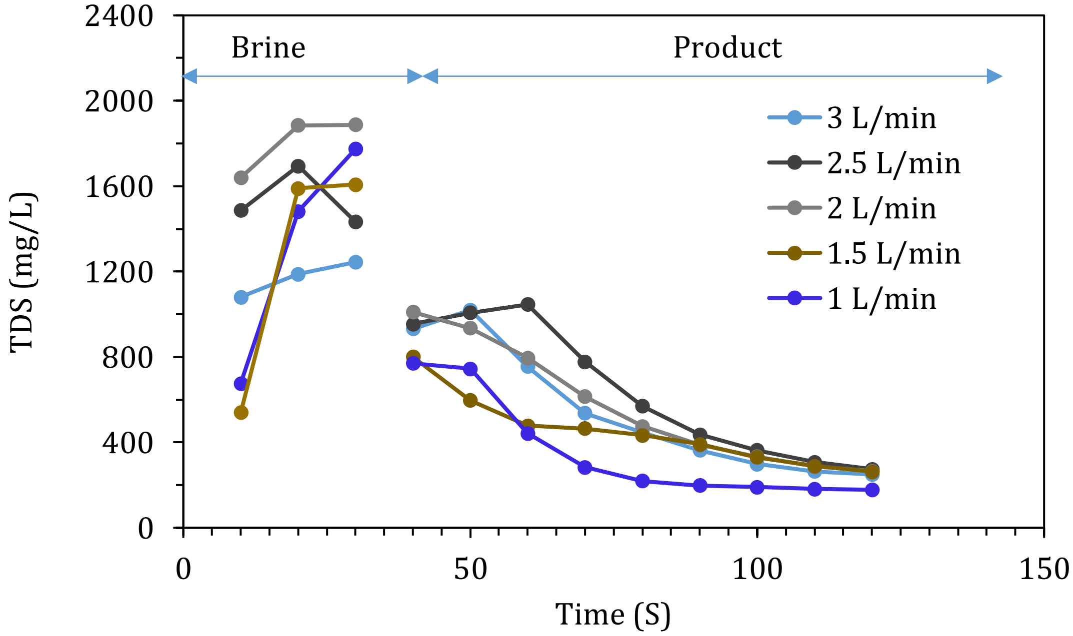


Figure B.1. The CDI cyclic performance at different flow rates for reclaimed water with GAC pre-treatment.

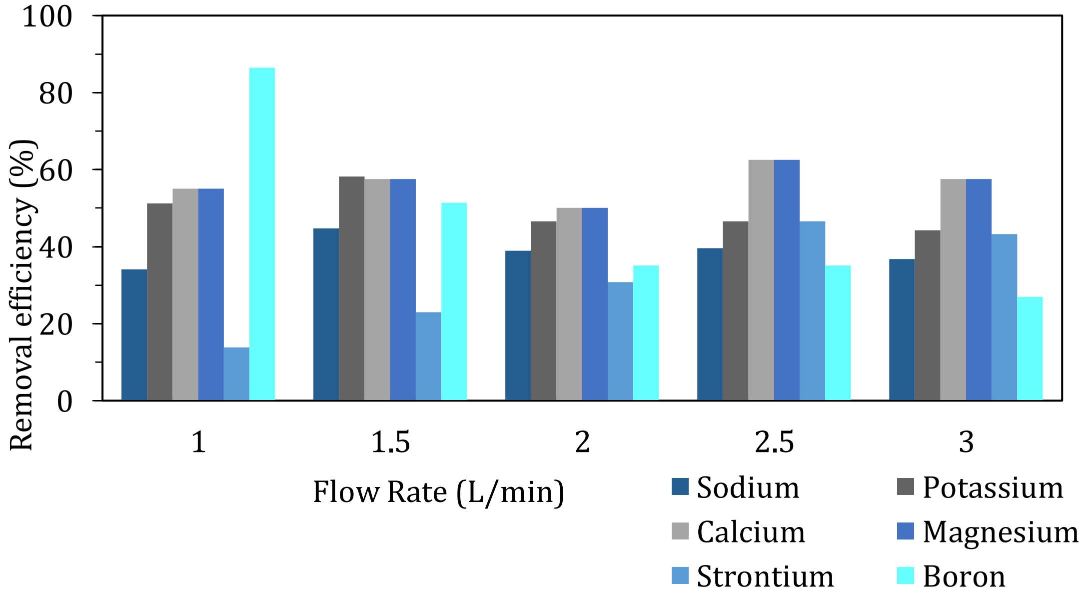


Figure B.2. Removal of major cations at different flow rates from reclaimed water with GAC pre-treatment. The trial of 1 L/min was run after the 3 L/min, prior to cleaning step.

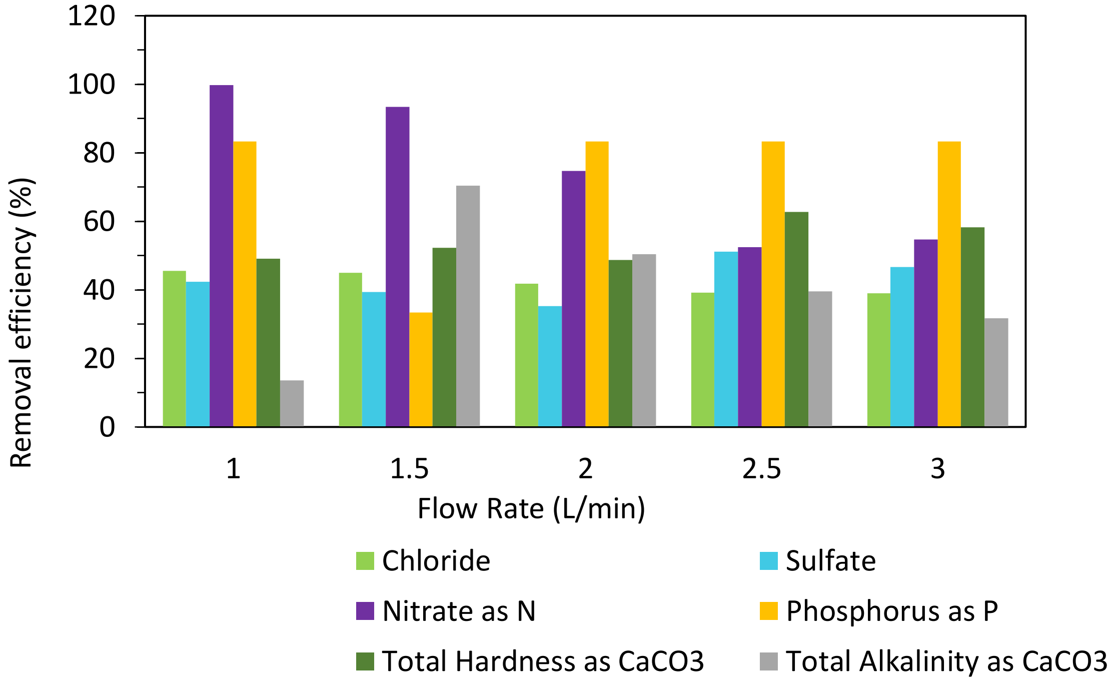


Figure B.3. Removal of major anions at different flow rates from reclaimed water with GAC pre-treatment.

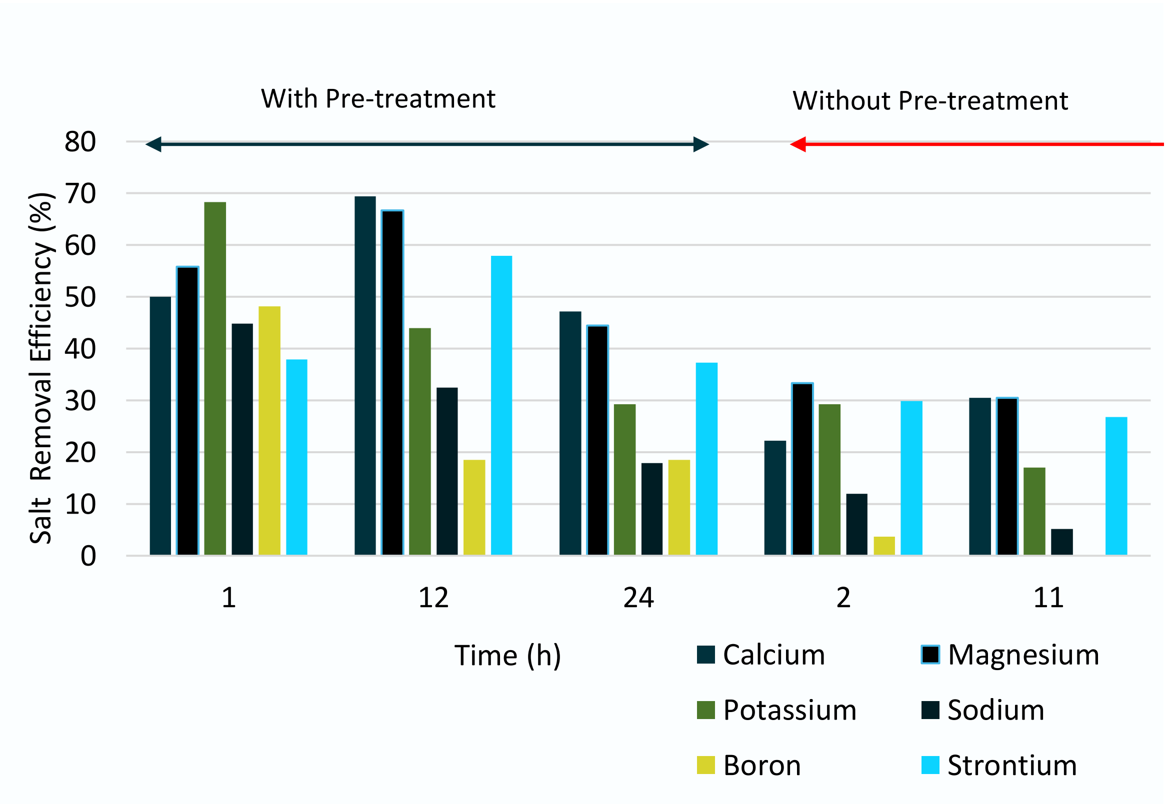


Figure B.4. Removal of major cations from reclaimed water over 24 h period.

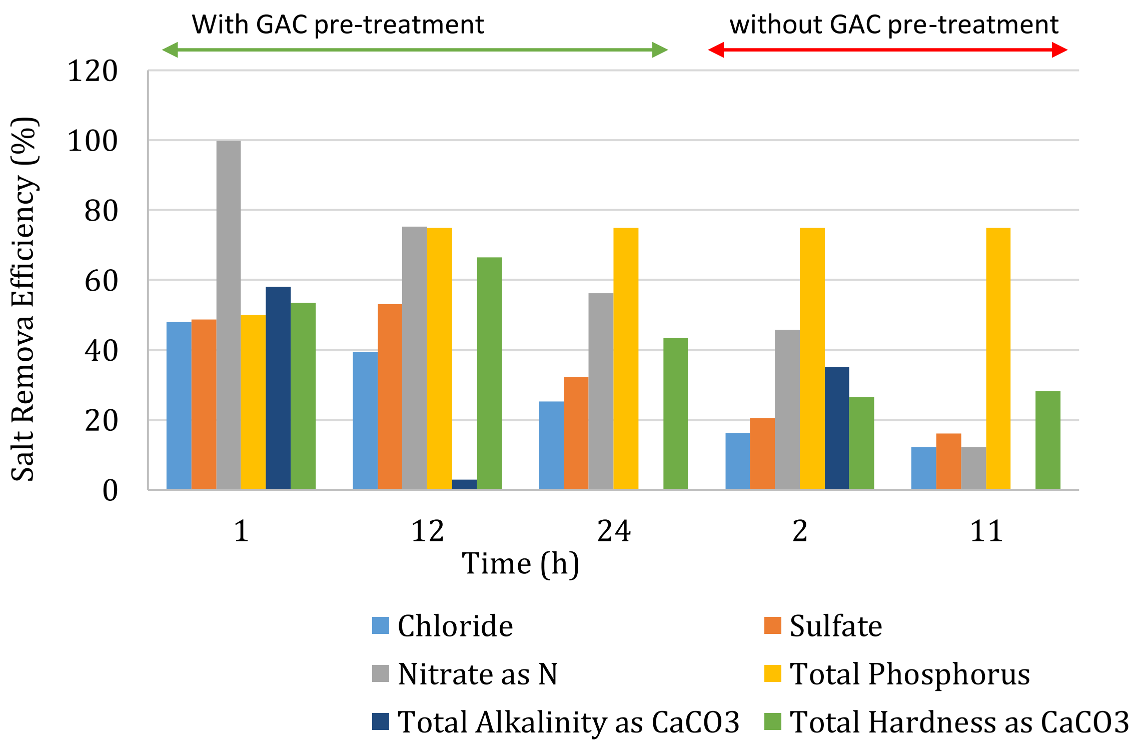


Figure B.5. Removal of major anions from reclaimed water over 24 h period.

__Analyses of bore water__

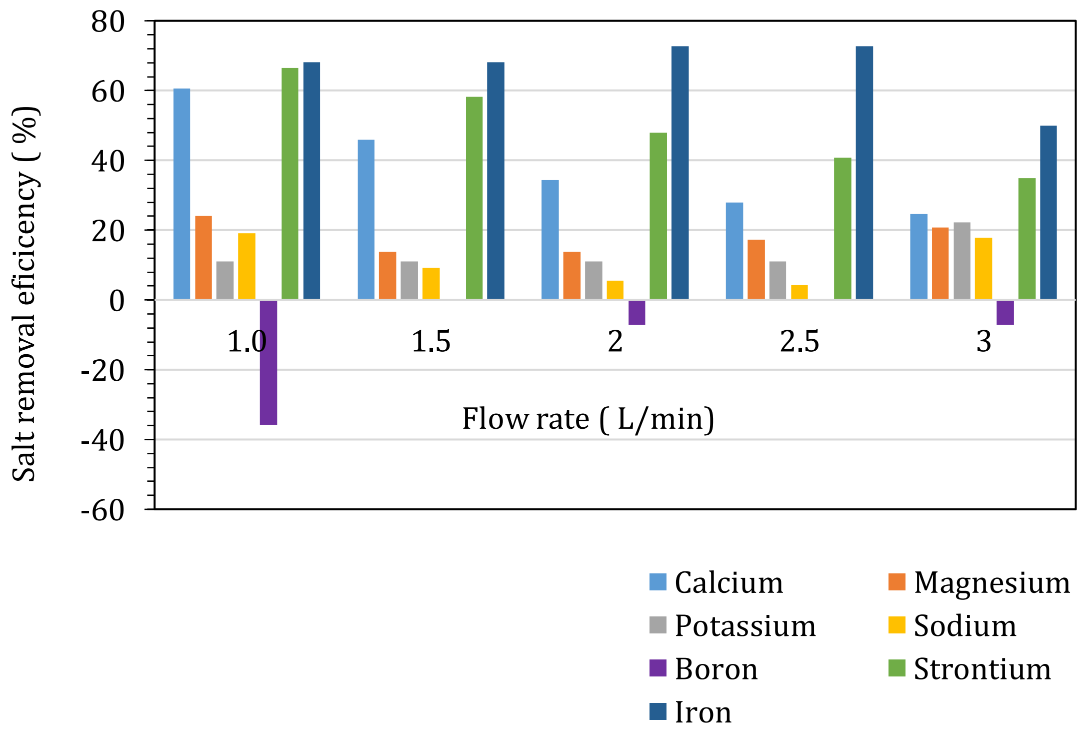


Figure B.6. Removal of major cations from bore water at different flow rates without GAC pre-treatment.

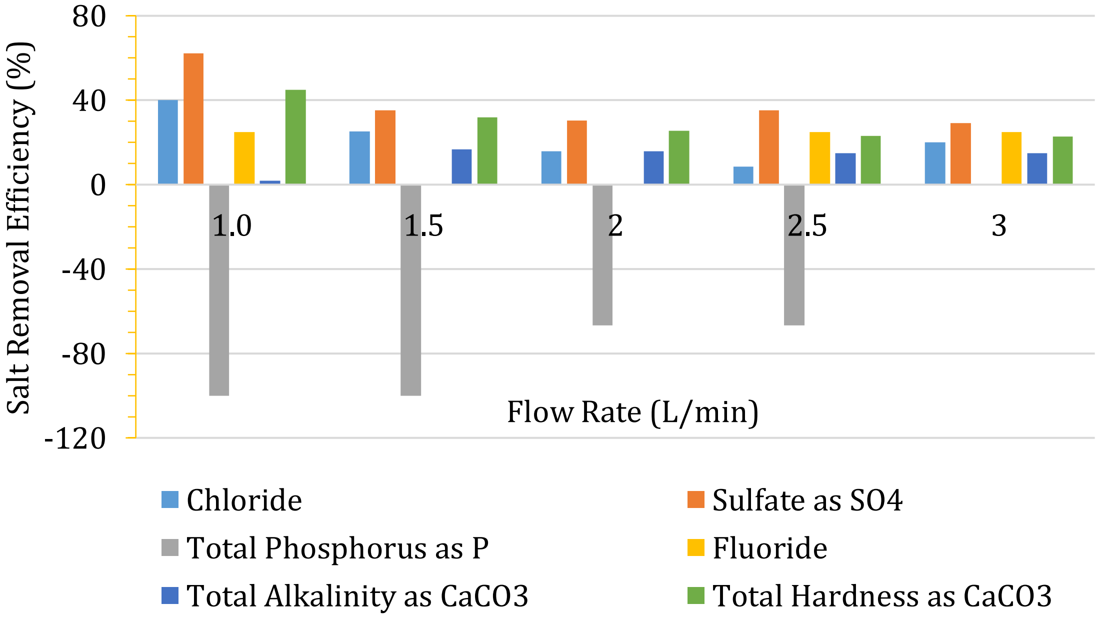


Figure B.7. Removal of anions from bore water at different flow rates without GAC pre-treatment. Total phosphorus includes organic bound P and under the trials without GAC pre-treatment, adsorbed organics onto the electrodes might have been subsequently released leading to the increases found).

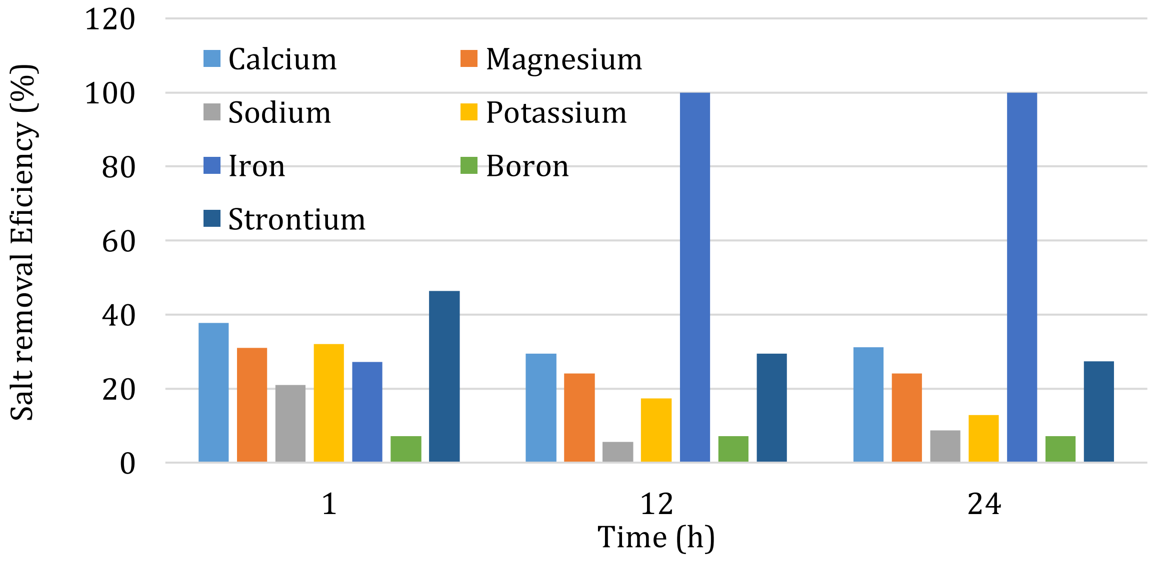


Figure B.8. Removal of major cations from bore water over 24 h period without GAC pre-treatment.

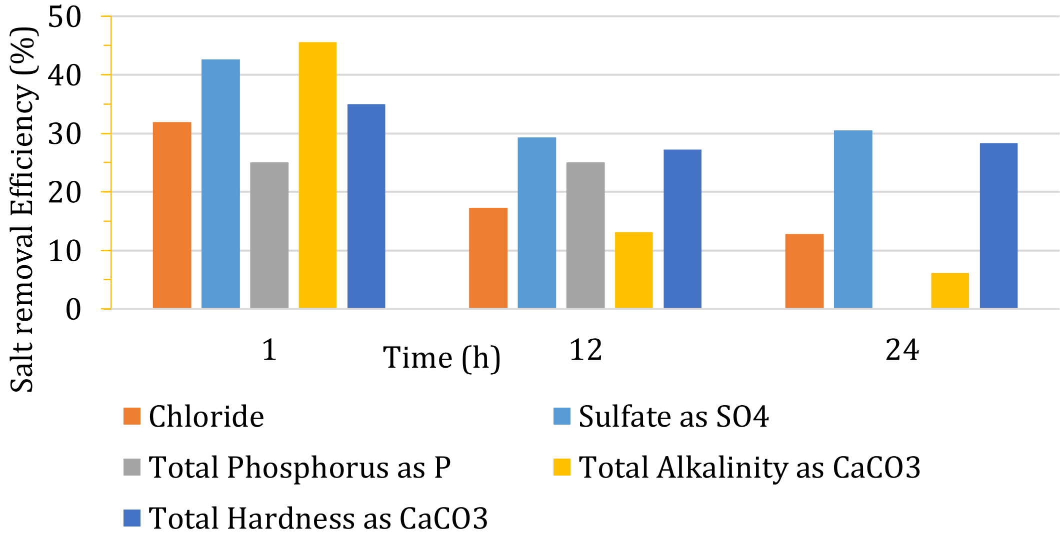


Figure B.9. Removal of anions from bore water over 24 h period without GAC pre-treatment.

Appendix C - laboratory water quality analysis reports

Table C.1. Analysis of Bolivar water samples at different flow rates.

Client - Matrix:	WATER		Sample Type:		REG													
Workgroup:	EM1705410		ALS Sample number:		EM1705410001	EM1705410002	EM1705410003	EM1705410006	EM1705410007	EM1705410009	EM1705410011	EM1705410012	EM1705410004	EM1705410005	EM1705410008	EM1705410010	EM1705410014	EM1705410013
Project name/number:	Water Samples		Sample date:		1/05/2017													
			Client sample ID (Primary): Client sample ID (Secondary): Sample Site: Purchase Order:		1-Raw	1-AGAC	1-ACDI	1.5-Raw	1.5-ACDI	2-ACDI	2.5-ACDI	3-Raw	1.5-AGAC20	1.5-AGAC	2-AGAC	2.5-AGAC	3-ACDI	3-AGAC
Analyte grouping/Analyte	CAS Number	Units	LOR															
EA005P: pH by PC Titrator																		
pH Value		pH Unit	0.01		7.61	8.22	6.89	7.47	5.52	6.37	6.94	7.56	----	----	----	----	7.06	----
EA006: Sodium Adsorption Ratio (SAR)																		
Sodium Adsorption Ratio			0.01		7.92	8.62	7.26	7.09	6.28	6.76	7.78	7.29	----	----	----	----	7.66	----
EA010P: Conductivity by PC Titrator																		
Electrical Conductivity @ 25°C		µS/cm	1		2220	1900	1210	1940	1130	1210	1190	1920	----	----	----	----	1240	----
EA015: Total Dissolved Solids dried at 180 ± 5 °C																		

Total Dissolved Solids @180°C		mg/L	10		1080	1030	731	1080	729	745	688	1080	----	----	----	----	721	----
EA065: Total Hardness as CaCO3																		
Total Hardness as CaCO3		mg/L	1		287	230	146	272	137	147	107	280	----	----	----	----	120	----
ED037P: Alkalinity by PC Titrator																		
Hydroxide Alkalinity as CaCO3	DMO-210-001	mg/L	1		<1	<1	<1	<1	<1	<1	<1	<1	----	----	----	----	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	mg/L	1		<1	<1	<1	<1	<1	<1	<1	<1	----	----	----	----	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	mg/L	1		139	190	120	128	41	69	84	131	----	----	----	----	95	----
Total Alkalinity as CaCO3		mg/L	1		139	190	120	128	41	69	84	131	----	----	----	----	95	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA																		
Sulfate as SO4 - Turbidimetric	14808-79-8	mg/L	1		201	207	116	206	122	130	98	205	----	----	----	----	107	----
ED045G: Chloride by Discrete Analyser																		
Chloride	16887-00-6	mg/L	1		467	407	254	432	257	272	284	431	----	----	----	----	285	----
ED093F: Dissolved Major Cations																		
Calcium	7440-70-2	mg/L	1		49	36	29	48	27	26	18	48	----	----	----	----	20	----
Magnesium	7439-95-4	mg/L	1		40	34	18	37	17	20	15	39	----	----	----	----	17	----
Sodium	7440-23-5	mg/L	1		308	301	203	268	170	188	186	280	----	----	----	----	195	----
Potassium	7/09/7440	mg/L	1		43	39	21	40	18	23	23	40	----	----	----	----	24	----
EG020T: Total Metals by ICP-MS																		
Copper	7440-50-8	mg/L	0.001		0.004	0.008	0.004	0.003	0.037	0.024	0.026	0.003	----	----	----	----	0.027	----
Manganese	7439-96-5	mg/L	0.001		0.011	0.001	0.03	0.032	0.027	0.024	0.014	0.044	----	----	----	----	0.017	----
Strontium	7440-24-6	mg/L	0.001		0.374	0.361	0.322	0.37	0.288	0.259	0.2	0.369	----	----	----	----	0.212	----
Zinc	7440-66-6	mg/L	0.005		0.021	0.049	5.1	0.031	8.46	3.86	1.95	0.027	----	----	----	----	1.61	----
Boron	7440-42-8	mg/L	0.05		0.37	<0.05	<0.05	0.34	0.18	0.24	0.24	0.37	----	----	----	----	0.27	----
Iron	7439-89-6	mg/L	0.05		<0.05	<0.05	0.44	0.06	0.46	0.22	0.11	<0.05	----	----	----	----	0.07	----

EG035T: Total Recoverable Mercury by FIMS																		
Mercury	7439-97-6	mg/L	1E-04		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	----	----	----	----	<0.0001	----
EK040P: Fluoride by PC Titrator																		
Fluoride	16984-48-8	mg/L	0.1		0.6	0.7	0.6	0.4	0.4	0.4	0.4	0.4	----	----	----	----	0.4	----
EK057G: Nitrite as N by Discrete Analyser																		
Nitrite as N	14797-65-0	mg/L	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02	<0.01	----	----	----	----	0.11	----
EK058G: Nitrate as N by Discrete Analyser																		
Nitrate as N	14797-55-8	mg/L	0.01		3.64	0.5	<0.01	6.98	0.24	0.92	1.73	7.28	----	----	----	----	1.65	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser																		
Nitrite + Nitrate as N		mg/L	0.01		3.64	0.5	<0.01	6.98	0.24	0.93	1.75	7.28	----	----	----	----	1.76	----
EK067G: Total Phosphorus as P by Discrete Analyser																		
Total Phosphorus as P		mg/L	0.01		0.06	0.14	0.01	0.04	0.04	<0.01	<0.01	0.03	----	----	----	----	<0.01	----
EN055: Ionic Balance																		
Total Anions		meq/L	0.01		20.1	19.6	12	19	10.6	11.8	11.7	19	----	----	----	----	12.2	----
Total Cations		meq/L	0.01		20.2	18.7	12.3	18.1	10.6	11.7	10.8	18.8	----	----	----	----	11.5	----
Ionic Balance		%	0.01		0.24	2.36	1.31	2.45	0.04	0.21	4.07	0.62	----	----	----	----	2.84	----
EP005: Total Organic Carbon (TOC)																		
Total Organic Carbon		mg/L	0.2		6.1	<0.2	37.2	5.5	62	41.7	24.4	5	30.1	26.4	21.9	20.3	22.6	18.2

Table C.2. Water quality analysis for Bolivar water for operation over 24 h.

Client - Matrix:	WATER	Sample Type:		REG	REG	REG	REG	REG	REG	REG
Workgroup:	EM1707796	ALS Sample number:		EM1707796001	EM1707796002	EM1707796003	EM1707796004	EM1707796005	EM1707796006	EM1707796007
Project name/number:	Water Samples	Sample date:		15/06/2017						
		Client sample ID (Primary):		GAC 1hr	GAC 12hr	GAC 24hr	NGAC 2hr	NGAC 11hr	RAW GAC	RAW N/GAC
		Client sample ID (Secondary):								
		Sample Site:								
		Purchase Order:								
Analyte grouping/Analyte	CAS Number	Units	LOR							
EA005P: pH by PC Titrator										
pH Value		pH Unit	0.01	5.68	7.01	7.2	6.48	7.04	7.36	7.57
EA006: Sodium Adsorption Ratio (SAR)										
Sodium Adsorption Ratio			0.01	6.23	8.98	8.4	7.9	8.59	7.69	7.66
EA010P: Conductivity by PC Titrator										
Electrical Conductivity @ 25°C		µS/cm	1	960	1150	1430	1480	1620	1860	1930
EA015: Total Dissolved Solids dried at 180 ± 5 °C										
Total Dissolved Solids @180°C		mg/L	10	608	605	804	846	905	1000	1040
EA065: Total Hardness as CaCO3										

Total Hardness as CaCO3		mg/L	1	107	77	130	169	165	230	230
ED037P: Alkalinity by PC Titrator										
Hydroxide Alkalinity as CaCO3	DMO-210-001	mg/L	1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	3812-32-6	mg/L	1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	mg/L	1	44	102	120	68	105	105	121
Total Alkalinity as CaCO3		mg/L	1	44	102	120	68	105	105	121
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA										
Sulfate as SO4 - Turbidimetric	14808-79-8	mg/L	1	105	96	139	163	172	205	203
ED045G: Chloride by Discrete Analyser										
Chloride	16887-00-6	mg/L	1	226	263	324	363	381	434	431
ED093F: Dissolved Major Cations										
Calcium	7440-70-2	mg/L	1	18	11	19	28	25	36	36
Magnesium	7439-95-4	mg/L	1	15	12	20	24	25	34	34
Sodium	7440-23-5	mg/L	1	148	181	220	236	254	268	267
Potassium	7/09/7440	mg/L	1	13	23	29	29	34	41	39
EG020T: Total Metals by ICP-MS										
Copper	7440-50-8	mg/L	0.001	0.34	0.06	0.045	0.254	0.168	0.005	0.004
Manganese	7439-96-5	mg/L	0.001	0.028	0.006	0.008	0.009	0.005	0.006	0.018
Strontium	7440-24-6	mg/L	0.001	0.183	0.124	0.185	0.207	0.216	0.295	0.321
Zinc	7440-66-6	mg/L	0.005	6.76	0.898	0.96	2.24	0.777	0.044	0.026
Boron	7440-42-8	mg/L	0.05	0.14	0.22	0.22	0.26	0.27	0.27	0.28
Iron	7439-89-6	mg/L	0.05	0.9	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

EG035T: Total Recoverable Mercury by FIMS											
Mercury	7439-97-6	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EK040P: Fluoride by PC Titrator										
Fluoride	16984-48-8	mg/L	0.1	0.6	0.3	0.3	0.4	0.3	0.3	0.4
EK057G: Nitrite as N by Discrete Analyser										
Nitrite as N	14797-65-0	mg/L	0.01	0.93	0.16	0.36	0.02	0.04	0.02	<0.01
EK058G: Nitrate as N by Discrete Analyser										
Nitrate as N	14797-55-8	mg/L	0.01	<0.01	2.71	4.81	5.96	9.65	11	8.81
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser										
Nitrite + Nitrate as N		mg/L	0.01	0.61	2.87	5.17	5.98	9.69	11	8.81
EK067G: Total Phosphorus as P by Discrete Analyser										
Total Phosphorus as P		mg/L	0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.04	0.02
EN055: Ionic Balance										
Total Anions		meq/L	0.01	9.44	11.4	14.4	15	16.4	18.6	18.8
Total Cations		meq/L	0.01	8.9	10	12.9	14.4	15.2	17.3	17.2
Ionic Balance		%	0.01	2.93	6.8	5.58	2.08	3.8	3.64	4.43

Table C.3. Analysis of bore water samples at different flow rates before and after desalination.

Client - Matrix:	WATER	Sample Type:		REG	REG	REG	REG	REG	REG	REG	REG
Workgroup:	EM1711319	ALS Sample number:		EM1711319001	EM1711319002	EM1711319003	EM1711319005	EM1711319006	EM1711319007	EM1711319008	EM1711319009
Project name/number:	Water Samples	Sample date:		22/08/2017							
		Client sample ID (Primary):		1	2	3	4	5	6	7	8
		Client sample ID (Secondary):									
		Sample Site:									
		Purchase Order:									
				Feed	Raw after cf	Raw	FR 1 after CDI	FR 1.5 after CDI	FR 2 After CDI	FR .5 after CDI	FR 3 repeat After CDI
Analyte grouping/Analyte	CAS Number	Units	LOR								
pH Value		pH Unit	0.01	7.82	----	7.88	7.53	7.26	7.28	7.38	7.35
Sodium Adsorption Ratio			0.01	4.37	----	4.28	4.64	4.7	4.67	4.67	4
Electrical Conductivity @ 25Â°C		ÂµS/cm	1	1390	----	1370	905	1050	1060	1120	981
Total Dissolved Solids @180Â°C		mg/L	10	741	----	769	552	588	685	639	614
Turbidity		NTU	0.1	2.8	0.6	1.9	----	----	----	----	----
Total Hardness as CaCO3		mg/L	1	282	----	272	150	185	203	209	210
Hydroxide Alkalinity as CaCO3	DMO-210-001	mg/L	1	<1	----	<1	<1	<1	<1	<1	<1

Carbonate Alkalinity as CaCO3	3812-32-6	mg/L	1	<1	----	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	mg/L	1	229	----	228	224	190	192	194	194
Total Alkalinity as CaCO3		mg/L	1	229	----	228	224	190	192	194	194
Sulfate as SO4 - Turbidimetric	14808-79-8	mg/L	1	90	----	82	31	53	57	53	58
Chloride	16887-00-6	mg/L	1	275	----	266	159	199	224	243	213
Calcium	7440-70-2	mg/L	1	62	----	61	24	33	40	44	46
Magnesium	7439-95-4	mg/L	1	31	----	29	22	25	25	24	23
Sodium	7440-23-5	mg/L	1	169	----	162	131	147	153	155	133
Potassium	7/09/7440	mg/L	1	10	----	9	8	8	8	8	7
Copper	7440-50-8	mg/L	0.001	0.002	----	0.014	0.029	0.053	0.031	0.031	0.088
Manganese	7439-96-5	mg/L	0.001	0.007	----	0.007	0.006	0.007	0.008	0.007	0.007
Strontium	7440-24-6	mg/L	0.001	0.595	----	0.612	0.205	0.256	0.319	0.362	0.398
Zinc	7440-66-6	mg/L	0.005	0.029	----	0.048	2.06	1.4	1.02	0.604	0.65
Boron	7440-42-8	mg/L	0.05	0.13	----	0.14	0.19	0.14	0.15	0.14	0.15
Iron	7439-89-6	mg/L	0.05	0.22	----	0.22	0.07	0.07	0.06	0.06	0.11
Mercury	7439-97-6	mg/L	0.0001	<0.0001	----	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fluoride	16984-48-8	mg/L	0.1	0.3	----	0.4	0.3	0.4	0.4	0.3	0.3
Total Phosphorus as P		mg/L	0.01	0.04	----	0.03	0.02	0.06	0.06	0.05	0.05
Total Anions		meq/L	0.01	14.2	----	13.8	9.61	10.5	11.3	11.8	11.1
Total Cations		meq/L	0.01	13.2	----	12.7	8.91	10.3	10.9	11.1	10.2
Ionic Balance		%	0.01	3.48	----	4	3.75	1.01	1.92	3.12	4.42

Table C.4. Water quality analysis for bore water for operation over 24 h.

Client - Matrix:	WATER	Sample Type:		REG	REG	REG	REG	REG	REG	REG
Workgroup:	EM1711319	ALS Sample number:		EM1711319001	EM1711319002	EM1711319010	EM1711319011	EM1711319012	EM1711319013	EM1711319004
Project name/number:	Water Samples	Sample date:		22/08/2017						
		Client sample ID (Primary):		1	2	9	10	11	12	1a
		Client sample ID (Secondary):								
		Sample Site:								
		Purchase Order:								
				Feed	Raw after cf	24 h run 1st h Product	24 h run 1st h Brine	24 h run 12th h Product	24 h run 12th h Brine	After cartridge filter
Analyte grouping/Analyte	CAS Number	Units	LOR							
EA005P: pH by PC Titrator										
pH Value		pH Unit	0.01	7.82	----	7.02	7.13	7.7	7.89	----
EA006: Sodium Adsorption Ratio (SAR)										
Sodium Adsorption Ratio			0.01	4.37	----	4.18	3.76	4.73	4.08	----
EA010P: Conductivity by PC Titrator										
Electrical Conductivity @ 25Â°C		ÂµS/cm	1	1390	----	899	1330	1130	1920	----
EA015: Total Dissolved Solids dried at 180 Â± 5 Â°C										
Total Dissolved Solids @180Â°C		mg/L	10	741	----	582	899	638	1020	----

EA045: Turbidity										
Turbidity		NTU	0.1	2.8	0.6	----	----	----	----	1.2
EA065: Total Hardness as CaCO3										
Total Hardness as CaCO3		mg/L	1	282	----	177	350	198	478	----
ED037P: Alkalinity by PC Titrator										
Hydroxide Alkalinity as CaCO3	DMO-210-001	mg/L	1	<1	----	<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	3812-32-6	mg/L	1	<1	----	<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	71-52-3	mg/L	1	229	----	124	158	198	290	----
Total Alkalinity as CaCO3		mg/L	1	229	----	124	158	198	290	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA										
Sulfate as SO4 - Turbidimetric	14808-79-8	mg/L	1	90	----	47	100	58	123	----
ED045G: Chloride by Discrete Analyser										
Chloride	16887-00-6	mg/L	1	275	----	181	307	220	397	----
ED093F: Dissolved Major Cations										
Calcium	7440-70-2	mg/L	1	62	----	38	76	43	104	----
Magnesium	7439-95-4	mg/L	1	31	----	20	39	22	53	----
Sodium	7440-23-5	mg/L	1	169	----	128	162	153	205	----
Potassium	7/09/7440	mg/L	1	10	----	6	9	8	13	----
EG020T: Total Metals by ICP-MS										

Copper	7440-50-8	mg/L	0.001	0.002	----	0.225	0.287	0.003	0.005	----
Manganese	7439-96-5	mg/L	0.001	0.007	----	0.006	0.011	0.005	0.01	----
Strontium	7440-24-6	mg/L	0.001	0.595	----	0.328	0.728	0.432	1.07	----
Zinc	7440-66-6	mg/L	0.005	0.029	----	1.44	2.36	0.455	0.948	----
Boron	7440-42-8	mg/L	0.05	0.13	----	0.13	0.14	0.13	0.12	----
Iron	7439-89-6	mg/L	0.05	0.22	----	0.16	0.17	<0.05	<0.05	----
EG035T: Total Recoverable Mercury by FIMS										
Mercury	7439-97-6	mg/L	0.0001	<0.0001	----	<0.0001	<0.0001	<0.0001	<0.0001	----
EK040P: Fluoride by PC Titrator										
Fluoride	16984-48-8	mg/L	0.1	0.3	----	0.3	0.3	0.3	0.5	----
EK067G: Total Phosphorus as P by Discrete Analyser										
Total Phosphorus as P		mg/L	0.01	0.04	----	0.05	0.06	0.08	0.06	----
EN055: Ionic Balance										
Total Anions		meq/L	0.01	14.2	----	8.56	13.9	11.4	19.6	----
Total Cations		meq/L	0.01	13.2	----	9.26	14.3	10.8	18.8	----
Ionic Balance		%	0.01	3.48	----	3.94	1.35	2.49	1.96	----

Appendix D - CDI Cost estimated obtained from AQUA, USA

AQUA EWP

1-Jan-17

Model		Dispenser (not available yet)	commercial	commercial	commercial	commercial	commercial	for containers or skids
			P-1 research unit	P-1CA	P2	P4	P8	P32
feed Flow instantaneous	lpm	0.25	0.25	5	10	20	40	160
feed Flow average	lph	12	12	150	480	960	1,920	7,680
Number of Cells		1	1	1	2	4	8	32
Ion Rejection @ max TDS		80%	depends on salinity	depends on salinity	depends on salinity	depends on salinity	depends on salinity	depends on salinity

Operating Parameters

Recovery		75%	75%	75%	75%	75%	75%	75%
Temperature	deg F	40 to 100	40 to 100	40 to 100	40 to 100	40 to 100	40 to 100	40 to 100
PH		4 to 9	4 to 9	4 to 9	4 to 9	4 to 9	4 to 9	4 to 9
Max. TDS	PPM	1000	100,000	3,000	100,000	100,000	100,000	100,000
Feed Pressure	PSIG	5	25	25	25	25	25	25

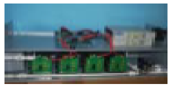
Unit Dimensions

W x D x H	inch	305 W x 318 D x 430 H	16" x 16" x 18 H"	20" x 20" x 30 H"	20" W x 20" H x 40 L"	20" W x 20" H x 40 L"	20" W x 20" H x 48 L"	24" D x 45" H x 45 W"
	mm		406 x 406 x 457 H	500 x 500 x 750 H	500" W x 500" H x 1000 L"	500" W x 500" H x 1000 L"	500" W x 500" H x 1200 L"	600 D x 1125 H x 1125 W
Shipping Weight	kg	10	22	30	30	36	45	180

Electrical Data

Electrical Voltage-single phase 50/60 hz	VAC*	120/240	120/240	240	240	240	240	240
power use @1,000 ppm	kwhr/m3	20 whr	0.3	0.3	0.3	0.3	0.3	0.3

Price		not for sale yet	$ 3,500	1 ea $3,000	$ 6,000	$ 8,000	$ 13,000	$ 50,000
				2 ea 2,500	citric acid PM $750	citric acid PM $750		
				12 ea 1,750	pump $1000	pump $1000		



Parts	major parts			
power suppy	n/a	600	750	1500
power distribution board	n/a	750	750	750
logic board	n/a	500	500	500
5.0 cell	n/a	900	900	900
citric acid clean	n/a	750	750 TBQ	

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide, the University of South Australia, and the International Centre of Excellence in Water Resource Management.