Australian Water Recycling
Centre of Excellence

Demonstration of robust water recycling: Final summary report

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Australian Water Recycling Centre of Excellence

S. Gray, J. Zhang, N. Milne, M. Duke, A. Knight, P. Scales, M. Allinson, G. Allinson, M. Packer, K. Northcott, P. Hillis, D. Sheehan, S. Allard, J. Tan, J-P Croué,
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Demonstration of robust water recycling: Final summary report

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About the Australian Water Recycling Centre of Excellence

The mission of the Australian Water Recycling Centre of Excellence is to enhance management and use of water recycling through industry partnerships, build capacity and capability within the recycled water industry, and promote water recycling as a socially, environmentally and economically sustainable option for future water security.

The Australian Government has provided $20 million to the Centre through its National Urban Water and Desalination Plan to support applied research and development projects which meet water recycling challenges for Australia's irrigation, urban development, food processing, heavy industry and water utility sectors. This funding has levered an additional $40 million investment from more than 80 private and public organisations, in Australia and overseas.

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Executive Summary

An advanced water treatment plant (AWTP) plant consisting of seven water treatment barriers was constructed to implement water recycling at Davis Station. The AWTP was constructed by the Australian Antarctic Division (AAD) and operated at Selfs Point Wastewater Treatment Plant (SPWWTP) in Hobart, Tasmania for approximately 10 months from August, 2014 to June, 2015. The AWTP will be installed at Davis Station during the summer of 2016/17 where it will treat membrane bioreactor (MBR) effluent.

The plant was fed secondary treated effluent while at SPWWTP, and the treatment train consisted of ozonation, ceramic microfiltration (MF), biological activated carbon (BAC), reverse osmosis (RO), ultra-violet disinfection (UV), calcite contactor and chlorination. The large number of barriers was required because a quantitative microbial risk assessment (QMRA) undertaken for this site considered pathogen loads at the treatment plant for outbreak conditions, which resulted in log removal value (LRV) targets of 12.1 for virus, 12.3 for bacteria and 10.4 for protozoa. These LRV are higher than the default Australian Guidelines for Water Recycling (AGWR) values because under disease outbreak conditions at Davis Station, a higher proportion of the population (40%) is likely to be ill, so that the pathogen concentrations arriving at the Davis Wastewater Treatment Plant will be higher than for larger scale municipal wastewater treatment plants.

The aims of the trial were to demonstrate the reliability of the treatment plant with regard to product water quality, effluent water quality, and ability of the plant to operate unattended, as well as to identify the maintenance requirements and energy consumption of the plant. The trial identified the following outcomes:

- Product water quality data and critical control points (CCPs) from the operation were consistent with production of potable quality product water.
- The RO concentrate (the AWTP waste stream) was of low environmental impact. This was supported by toxicity and bioassay data for the RO concentrate when compared to feed water.
- Measurement of trace organic compounds (TrOCs) throughout the process allowed novel chemical CCPs for the ozone and RO processes to be proposed. These CCPs required the same operating conditions as for pathogen removal.
- A pressure decay test (PDT) was used on the RO system to claim a LRV of 2 for protozoa, and it operated reliably throughout the demonstration.
- N-nitrosodimethylamine (NDMA) concentrations at key sampling points were below the ADWG limit of 100 ng/L, and NDMA concentrations in the product water were below the detection limit.
- Formaldehyde concentrations post-ozone, post-BAC and in the RO permeate were below the Australian Drinking Water Guideline (ADWG) maximum allowable concentration of 0.5 mg/L.
- Dosing of bromide (0.693 mg/L) and iodide (0.063 mg/L) into the feed demonstrated that the AWTP effectively removed bromide and iodide disinfection by-products and concentrations in the product water were below the ADWG limits. Therefore, feed waters with elevated bromide and iodide values can effectively be treated by the AWTP. Variations in DOC concentration and composition will be experienced when the plant is fed with MBR effluent at Davis Station and this will lead to changes in the concentration and mixture of disinfection by-products formed following ozonation. However, the high RO rejection demonstrated for disinfection by-products during the trials indicates that their concentrations in the RO permeate should remain low. Disinfection by-products were concentrated in the RO concentrate. There are no environmental discharge limits for these compounds, but toxicity and bioassay results indicated significantly lower activity levels for the RO brine than the AWTP feed. This

indicates the overall environmental impact of the RO brine is lower than that of the AWTP feed.

- The AWTP could be operated remotely and was able to automatically start and stop routinely. However, operation without skilled operator intervention has not yet been demonstrated and several plant components do not appear to have a suitably long service life. It is recommended that the identified components be replaced with high quality, longer service life components and that faults leading to skilled operator intervention be eliminated.
- Reliable and consistent operation of the demonstration plant during the August 2014 to June 2015 trials at Selfs Point could not be demonstrated. AAD are planning to operate the demonstration plant for a further 6-12 months and it is recommended that:
    1. the turbidity from the ceramic MF be monitored and the critical CCP turbidity value be reassessed with a view to lowering the critical turbidity value;
    2. the chlorination system be allowed to operate autonomously to demonstrate its reliability; and
    3. the plant demonstrate reliable autonomous operation, with only routine water quality verification and maintenance undertaken, by elimination of faults that require skilled operator intervention.
- Chemical inventories related to membrane washing and maintenance were lower than compared to a large scale plant being operated at higher flux.
- The RO membranes required cleaning about 3 times per year. Construction of similar AWTPs should consider extending the empty bed contact time (EBCT) of the BAC beyond 20 minutes to promote increased removal of biodegradable organic carbon (BDOC) by the BAC and thereby likely reduce RO biofouling. Consideration could also be given to placing the MF stage after the BAC so as to avoid the carry over to the cartridge filters that necessitated very frequent replacement, although additional cleaning of the ceramic MF may be required without an ozone residual in its feedwater.
- Identification of the specific ozone generator characteristics should be undertaken during installation if further plants are constructed, so that the upper power limits for the particular unit can be set in the control system. This will improve the reliability of operation.
- Removal of the ceramic MF from the process flowsheet may be possible if higher LRV can be claimed for the membrane bioreactor (MBR) (>2 LRV). This would enable a simplified AWTP process flowsheet to be used while still achieving the total system LRV required.
- The extra treatment barriers required for the high LRV and the need for lower environmental impact resulted in the energy consumption for water recycling being higher than conventional advanced water recycling systems. The AWTP used 1.93 $kW.h/m^3$ of energy when operated for 15 hours per day (12.6 kL/day), compared to a predicted 1.27 $kW.h/m^3$ for continuous operation at larger scale (10 ML/day). Installation of the AWTP at Davis Station, however, is expected to reduce energy consumption for the provision of water at Davis station by 69%, as currently cold, hypersaline water is desalinated to produce potable water.
- If AAD decides not to operate a water recycling system at Davis Station, improved discharged water quality could be achieved by the ozone and BAC processes alone. However, this will increase energy consumption as there is no offset in energy compared to current operations.

Recommendations

The following recommendations are made from the demonstration trials:

- A further 6-12 months of demonstration trials are required to verify that the plant can be operated with only annual or greater involvement by skilled operators. This requires rectification of faults that require skilled operator attention.
- A further 6-12 months of monthly NDMA testing be conducted using two different laboratories for NDMA analysis because of the unusually high NDMA rejections across the RO process determined in these trials.
- Time integrated passive sampling be investigated as a cost effective means for TrOCs monitoring on-site.
- Once the plant is installed at Davis Station, the following actions are recommended as part of the validation and verification required upon changing the feedwater to the AWTP, as it needs to be demonstrated that the feedwater water quality at Davis Station is similar to that at the trial site (Selfs Point Wastewater Treatment Plant):
  - Check the concentrations of Zn and other metals, and P, as well as the bioassay and toxicity values and compare these to the values for Selfs Point;
  - Undertake a water quality review of the feedwater, product water and other process streams as part of the commissioning process at Davis Station; and
  - Compare the water quality performance achieved by each treatment barrier (i.e. similar ceramic MF filtrate turbidity, etc.) to that achieved at Selfs Point, and review CCP target, alert and critical alarm values.

Chlorination of stored water at Davis Station be implemented prior to its distribution.

If further AWTPs are built, then the following design alterations be considered:

- Increasing the EBCT of the BAC to likely reduce biofouling of the subsequent RO process;
- Placing the MF stage after the BAC to reduce carbon fines passing to the RO units, however, additional cleaning of the ceramic MF may result from its feedwater not containing ozone;
- Including automated cleaning of the RO permeate lines to control biofilm growth;
- Increasing the residence time of the calcite contactor to provide greater final product water stability; and
- Constructing pipework and fittings downstream of the chlorination dosing point in plastic or other material less prone to corrosion.

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Nomenclature

AAD	Australian Antarctic Division
ADWG	Australian Drinking Water Guidelines
AGWR	Australian Guidelines for Water Recycling
ALS	Australian Laboratory Services
AWTP	Advanced water treatment plant
AWRCoE	Australian Water Recycling Centre of Excellence
BAC	Biological activated carbon
BDOC	Biodegradable organic carbon
BOD	Biological oxygen demand
CCP	Critical control point
CIP	Clean in place
CoC	Chemicals of Concern
CT	Concentration x time
DOC	Dissolved organic carbon
EBCT	Empty bed contact time
GC-MS	Gas chromatography mass spectroscopy
HACCP	Hazard analysis and critical control point
LC-MS	Liquid chromatography mass spectroscopy
LRV	Log removal value
MBR	Membrane bioreactor
MF	Microfiltration
NATA	National Association of Testing Authorities, Australia
NDMA	N-nitrosodimethylamine
PDT	Pressure decay test
QRMA	Quantitative microbial risk assessment
RO	Reverse osmosis
RWQMP	Recycled water quality management plan
SPWWTP	Selfs Point wastewater treatment plant
TDS	Total dissolved solids
TN	Total nitrogen
TOC	Total organic carbon
TrOC	Trace organic compound
TSS	Total suspended solids
UV	Ultra-violet disinfection

1 Introduction

Davis Station
The Australian Antarctic Division (AAD) undertook a study to assess the environmental impact[1] of macerated sewage discharge at Davis Station. The study identified an impact on the environment arising from pathogens, metals and hydrocarbons contained in the wastewater, and led AAD to upgrade their wastewater treatment system at Davis Station. AAD is also considering further upgrading the level of wastewater treatment to enable potable water recycling. Current water supplies in the Antarctic are drawn from a hypersaline tarn at Davis Station, and from melting of ice at Mawson and Casey Stations, which are very energy intensive and hence costly in this remote environment. Water recycling on Antarctic stations has the possibility to significantly reduce energy consumption and provide cost savings.

The Antarctic bases have a seasonal nature to their operations, with a larger number of staff during the summer season (November to April) and a reduced number of staff for the winter season (May to October). The population variation for Davis Station is shown in Table 1. As a result, the AWTP is required to deal with large changes in flow because of the seasonal population patterns.

Table 1: Davis Station population profile.

Station Population	Summer	Winter
Maximum	150	30
Average	120	25
Minimum	70	17

Station water use has risen from between 40 and 80 litres/person/day (L/p/d) in 2006/07 to 130-140 L/p/d in 2011. In 2015 water use had risen to 150 L/p/d and it is likely to be capped at this value. Using the population and water consumption data, an estimate of total water use per year is 4 ML, most of which will report to the wastewater system given outdoor use is minor.

Pathogen Removal Requirements
A membrane bioreactor (MBR) was chosen for secondary treatment of Davis Station wastewater, with its effluent provided to an advanced water treatment plant (AWTP). The AWTP is to produce potable water and discharge an effluent (RO effluent) with a lower environmental impact. A quantitative microbial risk assessment (QMRA) undertaken[2] prior to the AWRCoE project identified the required log reduction values (LRV) for small communities, and for Davis Station the required LRVs are: 12.1 for virus, 12.3 bacteria, and 10.4 for protozoa. These LRVs are higher than the default Australian Guidelines for Water Recycling (AGWR) values required for a larger municipal water recycling scheme (see Table 2), as the QMRA assumed that 40% of the population was sick during a disease outbreak. This is a reasonable assumption for small communities where people live and work closely with each other, but for larger communities the proportion of the community ill during a disease outbreak would be significantly smaller.

Plant Overview
An AWTP was designed and constructed to treat MBR effluent for production of drinking water and a final discharge effluent of lower environmental impact. The design assumed a constant feed flowrate of 20 L/min with intermittent operation. This flowrate allows treatment of all wastewater produced during the summer months, with operation every second day during winter. Initially, it was assumed that no LRV could be credited to the wastewater

MBR, as biological processes were required to be validated on-site and this was deemed impractical for Davis Station. The AWTP consisted of ozonation, ceramic microfiltration (ceramic MF), biological activated carbon (BAC), reverse osmosis (RO), ultra-violet disinfection (UV), a calcite contactor and chlorination. A schematic diagram of the process flowsheet is shown in Figure 1. Five of these seven unit processes were required to achieve the LRV for pathogens. These five barriers were ozonation, ceramic MF, RO, UV and chlorination. The BAC was included as an added barrier to chemicals of concern (CoC), the level of biodegradable dissolved organic carbon (BDOC) and, in particular, trace organic compounds (TrOC). The combination of ozone and BAC was expected to reduce the rate of fouling of the downstream RO membranes. The calcite contractor was used to restabilise the water and reduce downstream corrosion issues.

During commissioning trials at Selfs Point, it became apparent that ozone dosing was unable to provide a consistent ozone residual, and the claimed ozone LRVs were downgraded. This necessitated claiming of LRV for the MBR and the resultant claimed and credible LRV for each unit process is shown in Table 2.

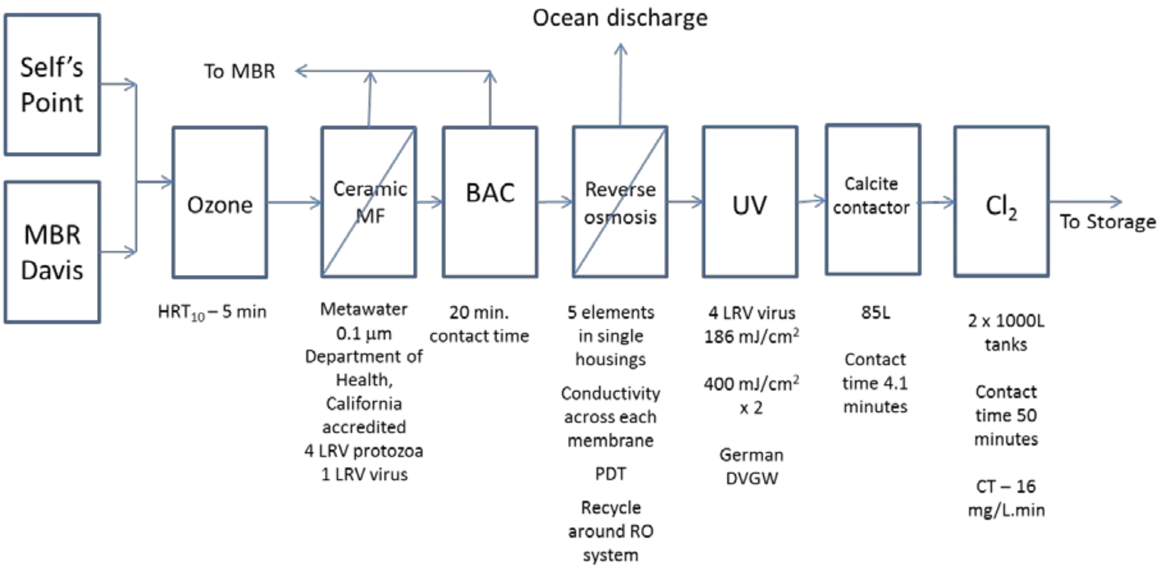

Figure 1: Schematic diagram of the AWTP Flowsheet

Project Plan

AAD's project plan included the operation of the AWTP plant in Australia for 12 months while the MBR wastewater treatment plant was installed and commissioned at Davis Station. The AWTP would then be taken to Davis Station and operated for at least another 12 months prior to AAD making a decision on whether to proceed with potable water recycling. A social acceptance study for determining the acceptability of potable recycled water to expeditioners is also being undertaken by AAD, but was not part of the AWRCoE project. The date for shipment of the AWTP to Davis Station was originally the summer of 2015/16 but was postponed to the summer of 2016/17 because of rescheduling of cargo on the goods vessel and changes in the construction program.

Operation of the AWTP in Australia rather than the Antarctic constituted the Australian Water Recycling Centre of Excellence (AWRCoE) project "Demonstration of Robust Water Recycling". The demonstration plant used for the AWRCoE project was constructed by AAD and is the same plant that will be taken to Davis Station. The delay in moving the AWTP to the Antarctic until the summer of 2016/17 has allowed the plant to be operated for a further 12 months in Australia prior to shipping to Davis Station.

Table 2: Claimed and credible LRV for each unit process.

Process	LRV					
	Virus		Bacteria		Protozoa	
	Claimed	Credible	Claimed	Credible	Claimed	Credible
MBR	2	3	2	4	2	4
Ozone	2	4	2	4	0	0
Ceramic MF	1	4	1	4	4	4
Biologically Activated Carbon (BAC)	0		0		0	
Reverse Osmosis	1.5	4	1.5	4	2	4
Ultra violet disinfection	4	4	4	4	4	4
Calcite Filter	0		0		0	
Chlorination	4	4	4	4	0	0
Total	14.5	23	14.5	24	12	16
Required for Davis Station[2]	12.1		12.3		10.4	

AGWR LRV values[2]	9.5	8.1	8.0

Project Scope and Objectives

For operational trials in Australia, the AWTP was located at Selfs Point Wastewater Treatment Plant (SPWWTP), Hobart, Tasmania. The trials undertaken were designed to verify the performance of the plant prior to shipment to Davis Station. The purpose of the trials was to:

1. Verify reliable water quality production by the AWTP over an extended period of time (approx. 12 months).
2. Demonstrate reliable operation of the plant, including maintenance requirements, sensor calibration frequencies, sensor reliability and barrier performance.
3. Produce an interim Recycled Water Quality Management Plan (RWQMP) and a Hazard Analysis and Critical Control Point (HACCP) analysis report to identify biological and chemical risks and to provide a management framework for operation.

The following detailed reports have been prepared during the AWRCoE project:

- *Operating Performance and Water Quality Report*, Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, August, 2015
- *Monitoring the levels of trace organic chemicals (TrOCs)*, Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, July 2015
- *Risk Assessment of the Removal of Chemicals of Concern in the Davis Station Advanced Water Treatment Plant*, Demonstration of robust water recycling, Australian Water Recycling Centre of Excellence, July, 2015
- *Interim operating manual,* Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, October, 2015
- *Operational Robustness of the Davis Station Advanced Water Treatment Plant, A*ustralian Water Recycling Centre of Excellence, July 2015
- *Energy Use and Comparison*, Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, October, 2015
- *Interim Recycled Water Quality Management Plan*, Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, October 2015
- *Hazard analysis and critical control point report*, Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, October, 2015
- *Pathogen log reduction value table*, Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, July, 2015
- *Feedwater Report*, Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, July, 2015
- *Experimental Plan*, Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, September, 2014
- *Functional Design*, Demonstration of Robust Water Recycling, Australian Water Recycling Centre of Excellence, July, 2015.

This report provides an overview of the outcomes from the project while the individual reports above provide a more detailed discussion of each topic. Discussion of the applicability of the AWTP to Davis Station and other locations is also included in this report.

2 Demonstration Plant Design and Methods

Selfs Point Wastewater Treatment Plant

The AWTP constructed by AAD was contained in two shipping containers, with the control system, compressor and storage housed in a 3rd shipping container. The AWTP was installed at the SPWWTP during May 2014 and operated until the end of May 2015. SPWWTP is a biological nutrient removal plant that operates both trickling filters and suspended growth treatment steps. Feed was sourced from the Selfs Point effluent channel prior to UV disinfection. A 2 mm screen was placed on the demonstration plant feed line to remove any large particles and flocs within the SPWWTP effluent. While water quality from SPWWTP was often stable with turbidity values ≤2 NTU, ammonia ≤1 mg/L and dissolved organic carbon (DOC) 8 mg/L, there were extended periods of time when maintenance activities on SPWWTP led to higher turbidity (3-5+ NTU) and ammonia (1-10 mg/L) but DOC remained unchanged. The AWTP on-site at SPWWTP is shown in Figure 2.

Figure 2: AWTP on site at SPWWTP.

Advanced Water Treatment Plant (AWTP)

The process design of the AWTP is outlined in the *Functional Design*[3]. The plant was operated at a continuous flowrate of 20 L/min during production phases. The control system considered a virtual tank that was filled at a rate lower than 20 L/min, and the plant operated until the level in the virtual tank fell to 500 L, at which point it went into standby. The plant recommenced production once the virtual tank level reached 3500 L. Operation in this manner was designed to simulate operation at Davis Station, where MBR effluent will fill a holding tank that activates and shut downs the AWTP on activation of high level and low level set points respectively. This configuration resulted in plant production for periods of approximately 6-7 hours before going into standby for approximately 4 hours. Consequently, there were many start-up and shut-down routines implemented. This regime was altered on occasions to allow continuous production during critical periods associated with sampling, as a shut-down would have resulted in non-representative sampling. This was particularly important for monthly micro-contaminant samples that were taken at a set time and day to allow sample preparation in a specific time period.

Water Quality Analyses
The sampling program and experimental protocols are detailed in the *Experimental Plan*[4]. The experimental runs focused on verification, and sought to identify the water quality of the final product water; water quality changes through the plant; the water quality of the RO concentrate; and the performance of unit processes (i.e. ability of ozone to maintain the set point residual, etc.).

Feedwater ammonia and phosphate concentrations, turbidity and pH were measured by TasWater on-line sensors in the effluent channel, and provided an indication of the feedwater quality. On-line water quality sensors within the AWTP were verified weekly by measurements taken from grab samples. Additional samples were also taken for verification of the on-line instruments and for checking the performance at locations elsewhere in the plant. The measurements included verification of on-line turbidity, conductivity and pH with handheld sensors calibrated on the day of sampling. Chlorine analysers were verified using a Hach spectrophotometer, analysis chemicals and procedures.

Water quality analyses were also performed weekly by TasWater's NATA accredited laboratory at Selfs Point. These analyses included Total Coliforms, *E. coli*, total dissolved solids (TDS), ammonia, nitrate, total nitrogen, biological oxygen demand (BOD), total suspended solids (TSS), alkalinity and UV absorption. Virus analysis was performed by the NATA accredited ALS laboratory in Melbourne following overnight delivery of samples, and biodegradable organic carbon (BDOC) was performed by Research Laboratory Services Pty Ltd following overnight delivery of samples.

Weekly samples were also taken for metals analysis, dissolved organic carbon (DOC) analysis and fluoride analysis at Victoria University. Anion analysis was not undertaken as planned, as characterisation of the feedwater indicated there was little variation of these compounds and all were at lower concentrations than specified in the Australian Drinking Water Guideline (ADWG). Similarly, some metals were consistently below the ADWG values, and were not analysed for after feedwater characterisation tests.

Further details on the sampling and analytical procedures are detailed in the DAWTP Experimental Plan[5] and the *Feedwater Report*[6], and identification of metals removed from the analyte list are detailed in the Feedwater Report[5]. Sampling and testing were reduced following several weeks of operation, as some data provided little additional value to understanding the operational performance of the plant (e.g. UV absorbance, etc.).

TrOCs, N-nitrosodimethylamine (NDMA), toxicity and bioassay analyses
TrOCs, NDMA, toxicity and bioassay analyses were performed on samples from up to 8 locations in the AWTP. The samples were sent stored on ice to the School of Chemistry at the University of Melbourne. All samples were prepared for analysis by solid phase extraction within 24-48 hours. Innovative gas chromatography mass spectrometry (GC-MS) and liquid chromatography mass spectrometry (LC-MS/MS) developed by Professor Kadokami (University of Kitakyushu) were used and together they could screen samples for more than 1200 TrOCs[6,7]. NDMA analyses were undertaken by the UNSW Water Research Centre. Toxicity of sample extract was conducted using the PB test method of Shiraishi et al. (1999)[8], which measures how much the sample has to be concentrated to inhibit luminescence in 50% of the photobacteria used in the test. Estrogenic and xenobiotic activity were measured with yeast two-hybrid recombinant receptor-reporter gene bioassay systems in accordance with the method of Shiraishi et al. (2000)[9]. Further details of the analytical methods are contained in *Monitoring the levels of trace organic chemicals (TrOCs)*[10].

Disinfection by-product analyses
Disinfection by-products were determined for trials that had low, medium and high concentrations of bromide and iodide added to the feedwater. The feedwater bromide and

iodide concentrations are shown in Table 3. Dosing of bromide and iodide was undertaken to challenge the AWTP performance with respect to treatment of feedwaters containing high concentrations of bromide and/or iodide, so the removal performance of the AWTP for these compounds could be identifed. The feedwater concentrations were chosen to represent indicative high bromide and iodide water sources.

Table 3: Feedwater bromide and iodide concentrations during sampling for disinfection by-products.

Dosing	Bromide (µg.L^{-1})	Iodide (µg.L^{-1})
Low	200 (natural feed)	9 (natural feed)
Medium	490	37
High	693	63

Samples were sent on ice to the Curtin Water Quality Research Centre at Curtin University, Perth for analysis. The samples were analysed by ion chromatography and GC-MS following various preparation techniques to determine bromide, iodide, bromate, iodate, specific adsorbable organic halides (*AOCl, AOBr and AOI),* ten trihalomethanes (THMs) and nine haloacetic acids (HAA). Details of the analyses are contained in the *Operating Performance and Water Quality* report[11].

3 Results

3.1 Operation

A detailed description of the AWTP operation is provided in both the *Operating Performance and Water Quality*[12] and in the *Operational Robustness of the Davis Station advanced water treatment plant*[13] reports. The performance of each unit process was considered based on its ability to satisfy the required critical control point (CCP) parameters, as was the ability of the plant to operate remotely and unattended. The sensor calibration requirements were also assessed.

Ozone
During commissioning, the ozone system suffered several failures with the ozone generator breaking and requiring repair. However, once the maximum power of the ozone generation system was matched to the individual ozone cell it performed reliably for the remainder of the trial. In this case, commissioning of the ozone system required individually tailored installation to ensure trouble free operation.

The quality of the SPWWTP effluent varied considerably during the trials because maintenance of the secondary settling tanks within SPWWTP required a tank to be taken out of service. On several occasions this resulted in elevated turbidity levels (3-5+ NTU c.f. 1-2 NTU during normal operation) and also elevated ammonia concentrations (1-10 mg/L c.f. <0.5 mg/L during normal operation). The DOC and metals concentrations did not vary during these events. The high ammonia concentrations did not appear to affect the performance of the AWTP, but high turbidity values (3-5+ NTU) led to reduced or no ozone residual concentrations being achieved. This was problematic for ozone operation, as the initial ozone LRV of 4 for bacteria and virus required a residual ozone concentration (0.4 mg/L) for calculation of a CT value (2.0 mg.min/L at 20ºC). However, monitoring of *E. coli* and phage inactivation across the ozone system identified that >2 LRV could be reliably claimed even when no ozone residual was detected. This enabled a reduced LRV of 2 to be claimed by a modified ozone CCP based on either a CT value or meeting a minimum required ozone dose. Operation at Davis Station will use MBR effluent to feed the AWTP, meaning high turbidity values would not be expected. Therefore, while the problems associated with lack of ozone residual are not anticipated to occur at Davis Station, the revised CCP will allow operation if this were to eventuate.

Ceramic Microfiltration (MF)
The ceramic MF performed reliably, with chemically enhanced backwashing with hypochlorite (50 mg/L every 15 backwashes) and sulphuric acid (pH=2 every 15 hypochlorite backwashes) preventing long term fouling and operational transmembrane pressure (TMP) increases. The pressure decay test (PDT) identified that the membrane retained its integrity throughout the trial, although a leaking isolation value did lead to failure of the PDT for a short period a time. A valve leak test was then instigated for each PDT to ensure that the measured pressure decay was indicative of membrane integrity alone.

Initial measurement of the ceramic MF filtrate resulted in turbidity values >0.2 NTU because of gas bubbles in solution and vibrations in the sampling line. The sampling point was moved from the filtrate line to the BAC vessel feed weir to provide additional time for gas to escape, and the lines and sampling pump were refined to minimise vibrations. At the end of the trials, the filtrate turbidity readings were <0.1 NTU, however, the CCP currently has a turbidity limit of 0.2 NTU. It is recommended that the plant operate for another 6-12 months to confirm that filtrate turbidity values <0.1 NTU can be reliably achieved and measured, and if so then the ceramic MF turbidity CCP be lowered accordingly.

Biological Activated Carbon (BAC)
BAC was included in the process train to remove micro-contaminants and reduce the amount of biodegradable organic carbon (BDOC). BDOC increased following ozonation of the AWTP feed and significant removal was achieved by the BAC. BDOC was reduced from approximately 4 mg/L following ozonation and ceramic MF treatment to 1.1-1.9 mg/L post BAC. BDOC values for biologically stable water vary with temperature, but the final BDOC concentrations were considerably above the 0.15 mg/L[14] and 0.3 mg/L[15] limits for biologically stable waters in distribution systems quoted by others. This suggests that lower BDOC concentrations than currently achieved post-BAC would significantly reduce the regrowth potential in the downstream RO system. Therefore, increasing the BAC empty bed contact time (EBCT) above the current 20 minutes may assist in reducing the final BDOC concentration and thereby in reducing downstream biofouling issues.

The filtrate turbidity was <0.2 NTU and iron, manganese and zinc were removed across the BAC likely due to oxidation and precipitation of these metals. Carbon fines were also observed in fouling of the downstream cartridge filter (see RO section) indicating regular loss carbon fines from the BAC.

Reverse Osmosis (RO)
It was originally hoped that cleaning of the RO membranes would only be required once or twice every year. However, biofouling due to high BDOC resulted in a requirement for RO clean-in-place (CIP) every 4-5 months resulting in approximately 3 CIPs per year. A longer EBCT in the BAC may assist in reducing BDOC and the subsequent biofouling of the RO system. The cartridge filter prior to the RO also required replacement every 2 weeks due to carbon fouling. This frequency of replacement was deemed acceptable by AAD because of the low cost of replacement elements. To reduce the frequency of cartridge filter replacement, the ceramic MF could be placed after the BAC although greater cleaning of the ceramic MF may result from its feedwater no longer containing ozone. The extent of additional ceramic MF cleaning will depend upon the flux of the ceramic MF and the current low flux of the ceramic MF suggests only minor additional cleaning would be required although this should be determined operationally.
Regrowth of microorganisms in the RO permeate lines was observed after 5 months operation. Following cleaning of these lines, further regrowth was not observed after 2+ month's operation. It is recommended that automated cleaning of the RO permeate lines be implemented to manage biofilm development post-RO.

A pressure decay test (PDT) was applied to the RO system to enable a LRV to be claimed for protozoa. This test operated reliably on the plant, and while bubbles did appear in the RO permeate following a PDT, there were no adverse effects on the RO system.

Ultraviolet Disinfection (UV)
No operational issues were experienced with the UV system and it operated reliably throughout the trials.

Calcite Contactor
The calcite contactor produced slightly aggressive water, as the average calcium carbonate precipitation potential was -8.55 mg/L calcium carbonate. A longer contact time in the calcite contactor would further stabilise the water and reduce corrosion issues at Davis Station. Treatment of 600,000L of water between calcite additions means the contactor can operate for several months before requiring top up of the calcite media. Increasing the residence time of the calcite contactor in future plants would reduce the aggressiveness of the product water by addition of more calcium carbonate.

Chlorination
The chlorination system was made operational late in the trials due to slow delivery of replacement dosing pump parts. Once the dosing system was operational, control and sequencing issues frequently arose and only a few weeks operation was achieved during the trials. A further 6-12 months of demonstration plant operation is required to verify the reliability of the chlorination system.

While not part of the trials, it is known that water at Davis Station is not currently chlorinated. It is, therefore, recommended that chlorination of the stored product water prior to distribution at Davis Station be implemented.

Energy Use
Energy use by the AWTP was affected by the intermittent operation of the plant, with energy consumption required to run the services (air compressor, hot water service) and control systems even when the plant was not operating. Therefore, the energy consumption per unit of treated water decreases with the volume processed by the AWTP. Based on 15 hours operation per day (12.6 kL/day), the energy consumption was 1.93 kWh/m^3, with a minimum value of 1.8 kWh/m^3 if operation is continuous. The energy consumption for provision of recycled water at larger scale (10 ML/day) was estimated to be 1.27 kWh/m^3, so this plant consumes more power than would be typically used. However, the AWTP includes both ozone-BAC as well as RO for reducing the environmental impact of the RO concentrate, and required more barriers to achieve the higher LRV required for the small community it services. Taking these factors into consideration, the increased energy consumption for water recycling at small scale seems reasonable. At Davis Station, water is currently provided by desalination of a hypersaline tarn. Water recovery across the recycling plant is 70%, so implementation of the AWTP would reduce energy consumption for water provision at Davis Station by 69%. This represents a saving of approximately 33,250 L of diesel for electricity generation each year[15].

Robustness
Operation of the AWTP was undertaken remotely, the plant was able to start and stop automatically for batch mode operation, had low chemical requirements compared to larger systems operating at higher flux, and the ease of maintenance and calibration of instruments and sensors were deemed sufficiently suitable for remote operation[13]. A key feature of the plant was to limit skilled operator involvement. However, this was not demonstrated for a sufficiently long period of time due to a small number of control, design and equipment issues. These were only overcome during the last 1-2 months of the project, and further demonstration of unattended operation over a longer period of time (6-12 months) is required to demonstrate local intervention from highly skilled operators on an annual or longer basis. Further, a number of components on the plant were not considered capable of operation for 20+ years. It is recommended that components not meeting this criterion be replaced with more appropriate materials, such as construction of pipework and fittings downstream of the chlorination dosing point in plastic or other material less prone to corrosion. AAD are continuing to operate the plant and a further 6-12 months operation is recommended to demonstrate improved reliability.

3.2 Water Quality - Trace Organic Compounds (TrOCs)

The demonstration plant was able to produce potable grade product water and a RO concentrate fit for disposal in the pristine Antarctic environment. Measured metals, disinfection by-products (DBPs) including NDMA, trace organic compounds, *E. coli* and virus in the product water were all below the ADWG guidelines. Low concentrations of DOC, P and TN were also consistently recorded for the product water.

Formaldehyde
Formaldehyde can be produced during ozonation. Formaldehyde concentrations post-ozonation, post-BAC and in the RO permeate were measured during November 2015 and all registered <0.1 mg/L formaldehyde. These concentrations were all less than the ADWG maximum allowable concentration of 0.5 mg/L for formaldehyde.

N-nitrosodimethylamine (NDMA)
N-nitrosodimethylamine (NDMA) concentrations following ozonation were between 40 and 63 ng/L, and concentrations reduced after BAC treatment by 17-69% (10-49 ng/L). NDMA concentrations in the product water were below the limit of detection because of high rejection by the RO membranes, and the concentrations in the RO concentrate were approximately 40-70 ng/L. The high rejection of NDMA was unusual, but consistent results were achieved for all 5 samples tested by UNSW. Low NDMA concentrations in the product water were also reported by Curtin University, although they also detected low NDMA concentrations in the RO feed. While the basis for the discrepancy in the RO feedwater concentration determined by UNSW and Curtin University is unclear, all NDMA concentrations measured were below the ADWG limit of 100 ng/L. As the RO rejections values for NDMA were unusually high, it is recommended that further NDMA testing be conducted for up to 6-12 months at monthly intervals and that analysis be conducted by two laboratories.

Trace Organic Compounds (TrOCs)
Two chromatographic-mass spectrometry techniques were used to screen for the presence of 1250 chemicals. Seventy trace organic compounds (TrOCs) were detected in the feed water, but this was reduced to only 15 chemicals in the product water. Comparisons between the TrOC concentrations in the product water and the ADWG maximum concentration limits were made, and if the ADWG did not specify a maximum limit then a risk assessment estimated a limit consistent with the tolerable risk limit of the ADWG. All detected chemicals in the product water were below the ADWG and estimated maximum concentration limits by at least 4 orders of magnitude. To enable on-site monitoring in remote locations, it is recommended that time integrated passive sampling be researched as a means for monitoring TrOC concentrations in feed, environmental discharge and product waters.

The suitability of the RO concentrate for discharge to the environment was also assessed using a similar suite of analyses. Again, the bioassay results showed limited activity for any of the specific receptors and the photobacterium toxicity test indicated very low levels of toxicity. Only 13 TrOCs were detected in the RO concentrate and all were at levels considered safe for fish and invertebrates.

Verification of TrOCs removal
Removal of TrOCs across each of the treatment barriers were assessed, and consistent results were obtained throughout the demonstration trials. CCPs for chemicals were proposed based on the removal values across the MBR, ozone and RO processes. The CCP criteria and operating parameters coincided with those required for pathogen removal, so extra CCP criteria specifically for chemicals removal were not required. The following specific LRV were claimed:

- A LRV of 1.0 is claimed for Total N and a LRV of 0.8 for hydrophobic organic chemicals for the MBR barrier with CCP requirements.
- A LRV of 1.0 is claimed for the ozone barrier for electron rich aromatic compounds and alkenes with CCP requirements.
- A LRV of 1.0 is claimed for the RO barrier for all compounds except: neutral hydrophilic molecules with a MW<200, for which a LRV of 0.5 is claimed; and neutral

hydrophobic molecules with a MW < 400, for which a LRV of 0.5 is claimed. The CCP requirements were the same as those specified for the claimed pathogen LRVs.

Bioassay

Bioassay tests for estrogenic, xenobiotic and aryl hydrocarbon activity using specific receptors in yeast cells, and a general toxicity test using a photobacterium, were also undertaken on the AWTP feed, RO concentrate and product water. The product water results indicated very low levels of activity for these receptors and very low levels of toxicity. These results support the suitability of the product water for potable purposes and for discharge of the RO concentrate to the environment.

Disinfection by-products

Disinfection by-product concentrations in the product water were all below the ADWG maximum allowable limits (all < 3 µg/L), and high rejections were achieved across the RO membranes (feedwater concentrations were all <610 µg/L). Disinfection by-products are generally not considered in guidelines for aquatic discharges, and therefore it was difficult to assess the impact of these discharges on the environment. Concentrations were higher in the RO concentrate than elsewhere in the treatment process, but the concentrations were still <620 µg/L and the toxicity and bioassay tests all showed lower activity for the RO concentrate than the AWTP feed. Therefore, the quality of the RO concentrate relative to the AWTP feed with respect to biological impact seems to have improved.

Metals, P, TN and DOC

The RO concentrate was high in metals, P, DOC, and TN compared to the ANZECC Guidelines for marine environments. Removal of the metals, P and TN is problematic, as they cannot be destroyed. However, the loads are small because of the low flowrate from the AWTP, and the RO concentrate discharge will be lower environmental impact than untreated wastewater because of the removal of TrOCs.

Hazard Analysis and Critical Control Point (HACCP)

Hazard Analysis and Critical Control Point (HACCP) workshops reviewed water quality risks for the AWTP. This program considered the sources, controls and removal efficiencies of contaminants, and led to the development of a water quality risk register that specifies risks and controls. The process highlighted the need for spill protocols and consideration of maximum packaging sizes for chemicals to control maximum spill volumes. CCPs for pathogens and chemicals were also developed through this process. The specification of chemical CCPs is novel and was based on the large amount of data related to TrOC removal across each barrier in the treatment process. The need for challenge testing of bromide and iodide concentrations at concentrations that might be found in groundwater was identified and performed. These challenge tests demonstrated that bromide and iodide disinfection by-products were effectively removed from the product water via the RO process, and that feedwaters with bromide ≤ 0.693 mg/L and iodide ≤ 0.063 mg/L were suitable for producing potable quality product water.

Recycled Water Quality Management Plan (RWQMP)

An Interim Recycled Water Quality Management Plan (RWQMP) was drafted for AAD that specifies requisite implementation and operational policies, accountable persons and CCPs. This document provides a framework for effective management of the water recycling scheme. The Interim RWQMP will assist AAD in understanding their on-going responsibilities should they decide to implement the recycling scheme.

Recommendations

While suitable AWTP product and RO concentrate water quality has been demonstrated for Selfs Point Wastewater Treatment Plant, feed water quality at Davis Station will be different.

Therefore, as part of the validation and verification program following changing of the feedwater quality, the following actions are recommended:

- Check the concentrations of Zn and other metals, and P, as well as the bioassay and toxicity values and compare these to the values for Selfs Point.
- Undertake a water quality review of the feedwater, product water and other process streams as part of the commissioning process at Davis Station, including a measurement of ozone demand to verify that the ozonator is of adequate size to generate the appropriate ozone residual.
- Compare the water quality performance achieved by each treatment barrier (ie. similar ceramic MF filtrate turbidity etc) to that achieved at Selfs Point, and review CCP target, alert and critical alarm values.

4 Treatment for effluent discharge at Davis Station

The *Demonstration of Robust Water Recycling* project aimed to demonstrate the opportunity for reliable, potable water production in a remote community, specifically Davis Station in the Antarctic, as well as reduction of the environmental impact of wastewater discharges. The key concern for AAD has been the reduction of environmental effects, and the opportunity for potable water recycling is considered an additional bonus of more extensive treatment. However, the decision to implement a potable water recycling scheme has not been made by AAD and recycling may not proceed for non-technical reasons. For instance, there is a study of the likely acceptance of recycled water in Antarctic Stations for which the outcomes are currently unknown. Therefore, consideration should be given to not only implementation of a potable water recycling system, but also what process would be best suited for the reduction of environmental impact in the absence of the need for potable water recycling.

Installation of a MBR at Davis Station will improve the quality of wastewater for discharge to the ocean, but will not reduce the concentration of TrOCs to the same extent as the AWTP has demonstrated. The TrOCs report identifies significant decreases in photobacterium test toxicity and receptor activity for bioassay tests from the AWTP feed to RO concentrate discharge. Additionally the concentration of TrOCs by the two chromatographic-mass spectrometric screening tests reported a decrease in TrOC concentrations of approximately 95% between the AWTP feed and post-BAC. The ozonation and BAC combination is commonly used for TrOC removal and it also appears effective in the AWTP. The location of a ceramic MF between the ozone and BAC processes was reported by this study to remove significant amounts of TrOCs, but it is unclear if these would be otherwise removed by the BAC if the ceramic MF were removed. Also, the ceramic MF is likely removing turbidity from the Selfs Point wastewater and any TrOCs associated with these particles. Implementation of a MBR at Davis Station would reduce the turbidity and associated particles prior to the ozone process and thereby diminish any TrOCs removal by the subsequent ceramic MF.

Hence, for treatment of wastewater solely for discharge to the ocean, the AWTP could be simplified by directly discharging effluent following the BAC. It is likely that the ceramic MF could also be removed - although confirmatory evidence of this possibility is currently not available. Discharge of the effluent after the BAC would reduce the energy consumption of the plant including ancillary equipment to 1.17 kW/m^3. Removal of the ceramic membrane would have negligible effect on the energy consumption but would reduce the need for CIP chemicals, and combined with the removal of RO and chlorination would mean no imported chemicals were required for operation of the plant. However, the energy savings from recycling of water would not be achieved, and total energy consumption for Davis Station would increase as potable water would still need to be sourced exclusively from the hypersaline tarn, and wastewater treated more extensively. Overall the energy consumption for Davis Station would be increased by 1.17 kWh/m^3 associated with the additional treatment required prior to disposal.

5 Applicability to other locations

The AWTP for potable water recycling was designed for small, remote communities. In the context of Davis Station, the winter community size was sufficiently small (~20 people) that a high rate of infection amongst the total community (40%) was considered during outbreak conditions for the QMRA. The high rates of infection considered elevated the required LRV by approximately 2-4 log when compared to the default LRVs required for average municipal wastewater treatment plants, and thus drove the inclusion of additional treatment barriers beyond that required for larger scale water recycling plants. Additionally, the Davis Station wastewater system comprises a pressurised sewerage system, which negates infiltration so that there is no dilution of sewage in the Davis wastewater collection system. Coupled with this, no access to the Station is possible for 6 months of the year, thereby raising the significance of such disease outbreaks and warranting a conservative approach to setting LRV targets. At other locations, the impact of a disease outbreak may be less significant, or the likelihood of a significant proportion of the community becoming ill may be smaller, so that the default AGWR LRV targets shown in Table 2 could be used. Therefore, proponents of small, remote schemes should consider these issues when setting target LRV values.

At the commencement of the project, claimed MBR LRV without on-site testing would have provided only 0.5 LRV or less. It was considered that onsite validation for MBR at Davis Station was impractical because it has no ready access to laboratory facilities and expertise. However, during the project, the AWRCoE NatVal project undertook extensive testing for pathogen rejection from operating MBRs and demonstrated higher LRVs at the 95% confidence level[16]. This suggested that 2 LRV may be claimed across the MBR as shown in the revised LRV Table (see Table 2). Indeed, 2 LRV is claimed for virus but higher LRV has been demonstrated for protozoa and bacteria (LRV 4+) due to their larger size[17]. It should be noted that while there are data that may support the use of a default 2 LRV for pathogen removal by MBR processes, the final MBR LRV default values are yet to be approved by regulating authorities. The required LRV target will be able to be met even if this LRV target is lowered, as the total LRV currently claimed by the AWTP process is greater than the target values as shown in Table 2. It should also be noted that if 4 LRV for protozoa could be claimed across the MBR, as suggested by the NatVal project[7], then this would allow the ceramic MF to be removed from the process train without impacting the ability of the AWTP to reach the required LRV for small communities.

Water quality will also impact AWTP performance, and the current site demonstrated performance for a low salinity wastewater effluent following biological nutrient removal, and for a feed with low bromide and iodide concentrations. Elevated feed concentrations of bromide and iodide up to 0.693 mg/L and 0.063 mg/L respectively, produced disinfection by-products that were rejected by the RO membrane and discharged with the RO concentrate as discussed previously in the disinfection by-products section.

Higher salinity source waters will increase the pressure required for RO treatment and hence, increase energy consumption in-line with the higher osmotic pressure associated with such streams. However, the salinity of wastewaters seldom exceeds 1,000 mg/L TDS and generally similar performance might be expected at Davis Station. The salt composition may affect performance, with carbonates (alkalinity) acting as free radical scavengers and hence affecting ozonation efficiency. Scaling salts such as high levels of iron or manganese would generally be removed in upstream aerated biological processes, so significant increases in these parameters are not anticipated.

The project, therefore, demonstrated the most extensive water treatment likely to be required for producing purified water from treated wastewater at a remote site, and application at other sites may use this design. Alternatively a simplified version may be applied if higher LRV can be claimed for MBR treatment, and/or a lower target LRV is permitted (e.g. based on average pathogen concentrations at the wastewater treatment plant).

The project also demonstrated that a plant of this design was able to be started and stopped remotely and to operate in batch mode to cater for seasonal variations in feed volumes as may be typical for a small community. However, intervention by a skilled operator was required more regularly than desired and some components of the plant did not appear to have a long service life[13]. While these issues were being addressed at the end of the current trial, continued operation is recommended to demonstrate that the operation can be reliable over an extended period of time (6-12 months). The chemical inventory for the plant is such that chemicals for membrane cleaning and maintenance were significantly reduced as compared to a large scale plant being operated at high flux and high fouling rates.

6 Conclusions and Recommendations

An AWTP plant for purified water production in remote communities was demonstrated. The plant was constructed by AAD and operated at SPWWTP in Hobart, Tasmania for approximately 12 months.

All water quality data and CCPs from the operation were consistent with production of potable quality product water and a RO concentrate of low environmental impact. This was supported by toxicity and bioassay data for the product, RO concentrate and feed water streams, with the product water and RO concentrate toxicity and bioassay receptor activity results being very low. In comparison, the secondary effluent from SPWWTP had significantly higher toxicity and bioassay receptor activity. TrOC concentrations were measured throughout the process, and this allowed chemical CCPs for the ozone and RO processes to be proposed using operating conditions also required for pathogen removal. Specification of CCPs for chemicals is novel and had not been considered previously. For on-site monitoring of TrOCs, additional research on the use of time integrated passive samplers is recommended.

A novel PDT was used on the RO system to claim an LRV of 2 for protozoa. The PDT had no adverse effects on the RO system and operated reliably throughout the demonstration.

The use of ozone as the first treatment barrier led to disinfection by-product formation, and these compounds were predominantly discharged in the RO concentrate. NDMA formed by ozone was effectively removed by BAC and RO, with NDMA concentrations in the product water being below the detection limit. The NDMA concentrations after ozonation were also below the 100 ng/L ADWG limit. However, the unusually high RO rejections observed during these trials led to a recommendation that further monthly NDMA monitoring be undertaken for up to 12 months using two different analytical laboratories to independently verify the high NDMA rejections.

Elevated concentrations of bromide (0.693 mg/L) and iodide (0.063 mg/L) where introduced to the feed, and bromide and iodide disinfection by-products in the product water were below the ADWG limits. Hence, source waters with high bromide and iodide could be effectively treated by the AWTP.

Analyses for formaldehyde formation and removal identified that formaldehyde concentrations were significantly lower than the ADWG maximum allowable concentration.

A key design feature of the plant was to limit operator involvement, but this was not demonstrated for a sufficiently long period of time due to a small number of control, design and equipment issues. These were only overcome during the last 1-2 months of the project, and further demonstration of unattended operation over a longer period of time (6-12 months) is required.

AAD are planning to operate the demonstration plant for a further 12 months to achieve this. It is recommended that during the further 12 months of operation:

1. the turbidity from the ceramic MF be monitored and the critical CCP turbidity value be reassessed with a view to lowering the critical turbidity value;
2. the chlorination system be operated autonomously to demonstrate its reliability; and
3. the plant demonstrate reliable autonomous operation with only routine water quality verification and maintenance undertaken.

An aim of the demonstration was to operate the RO membranes with minimal need for cleaning, and it was hoped that cleaning of the RO membranes could be extended to annual events. However, biofouling occurred on the RO membranes and cleaning was required about 3 times per year. Extension of the EBCT of the BAC beyond 20 minutes may assist in decreasing the BDOC values post BAC, and thereby reduce the rate of RO membrane biofouling. This should be considered if further plants are constructed. Placement of the ceramic MF after ozone-BAC may reduce the replacement frequency of cartridge filters prior to RO although additional cleaning of the ceramic MF may result as its feedwater would no longer contain ozone. The significance of any additional ceramic MF cleaning arising from placement of MF after the BAC would need to be determined through operational trials, but the current low flux of the ceramic MF suggests only minor additional cleaning requirements.

Characterisation of the maximum power load of the specific ozone system being implemented should be undertaken during pre-commission when further plants are constructed, as failure to do this initially was a source of unreliable ozone operation during the commissioning phase of the project.

Improved knowledge regarding the ability of MBR to achieve high LRV may enable a simplified AWTP process flowsheet to be used, as claiming higher LRV for MBR could remove the need for a ceramic MF in the process. This simplification would still ensure the design was suitable for achieving the high target LRVs used for Davis Station. However, locations that have higher populations or can justify the use of average pathogen loads rather than outbreak concentrations may also have a simplified process flowsheet for the AWTP, as these factors reduce the target LRV for the recycling system.

The energy consumed in producing recycled water by the AWTP was approximately 1.93 kW.h/m^3 when operated for 15 hours per day. This is higher than the energy consumption of traditional water recycling processes and arises from the extra treatment required to reduce the environmental impact of the RO brine and to meet the high LRV required. However, installation of the AWTP at Davis Station has the potential to reduce energy consumption for the provision of water at Davis Station by 69%, as the current Davis Station water plant treats cold, hypersaline water.

AAD is yet to commit to a purified water scheme at Davis Station. If the decision is made to not implement a purified water system, the ozone and BAC processes could still be used to improve water quality prior to discharge of wastewater. However, in this instance the energy savings associated with the use of AWTP product water would not be realised and energy consumption would increase by 1.17 kWh/m3 because of the additional wastewater treatment implemented prior to disposal.

As part of the verification and validation program to establish that the Davis Station and Selfs Point feedwaters to the AWTP lead to similar performance of the AWTP, the following actions are recommended:

- Check the concentrations of Zn and other metals, and P, as well as the bioassay and toxicity values and compare these to the values for Selfs Point;
- Undertake a water quality review of the feedwater, product water and other process streams as part of the commissioning process at Davis Station; and
- Compare the water quality performance achieved by each treatment barrier (ie. similar ceramic MF filtrate turbidity, etc.) to that achieved at Selfs Point, and review CCP target, alert and critical alarm values.

While outside the scope of the AWTP plant, chlorination of stored water prior to its distribution at Davis station is also recommended.

If further AWTPs are built, then the following design alterations should be considered:

- Increasing in the EBCT of the BAC to reduce biofouling of the subsequent RO process;
- Including automated cleaning of the RO permeate lines to control biofilm growth;
- Increasing the residence time of the calcite contactor to improve water stability; and
- Construction of pipework and fittings downstream of the chlorination dosing point in plastic or other material less prone to corrosion.

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