Australian Water Recycling
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Demonstration of robust water recycling: Operational Robustness of the Davis Station Advanced Water Treatment Plant

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Demonstration of robust water recycling: Operational robustness of the Davis Station advanced water treatment plant

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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

The Advanced Water Treatment Plant (AWTP) for Australian Antarctic Division's (AAD) Davis Station was located at Selfs Point Wastewater Treatment Plant (SPWWTP), Hobart, to demonstrate its performance and reliability. This report overviews the reliability and robustness against a set of pre-formed criteria. The AWTP had seven functional barriers including ozone (O_3), microfiltration (MF), biological activated carbon (BAC), reverse osmosis (RO), UV, calcite contactor and chlorination (Cl_2) and is preceded by a Membrane Bioreactor (MBR). The conclusions from the work are based on demonstrated results from the trial and an analysis of likely differences between the trial case and when the plant is located at Davis Station. The report seeks to identify if the plant could be operated remotely and with minimal operational intervention from highly skilled personnel on-ground. It does not exclude remote advice from highly skilled personnel.

The main outcomes and recommendations from this report are:

- The AWTP is judged to meet the criterion to be operated remotely.
- The plant is judged to meet the criterion to be able to start and stop automatically and operates in batch mode to cater for variations in feed volumes seasonally as may be typical of a small community.
- The plant is judged to be not meeting the criteria that it could be operated for an extended period whereby intervention from highly skilled personnel would not be required locally or only attend on an annual or bi-annual visit. It is recommended that the plant be operated for a further trial period to reduce fault types that would require such an intervention.
- The water quality of the product and discharge streams of the plant are judged to be meeting the criteria that the product water should meet the requirements for potable water as laid out in the Australian Guidelines for Water Recycle and the discharge is safe for the marine environment.
- The AWTP is judged to be of low chemical inventory in that the quantity and type chemicals for membrane CIP are reduced as compared to a large scale plant being operated at high flux and higher fouling rates.
- The energy use of the plant was judged to be significantly less than current AAD operations for the production of potable water with potential savings of up to 30,000 L of diesel per annum. Estimates of energy use for deployment at a larger scale indicates a competitive scenario to brackish water desalination for brackish waters with >5 g/L salts.
- The ease of maintenance of calibration of sensors and instruments was judged to meet the criterion for remote operation but a number of the fixtures in the AWTP were considered to not meet the criterion that the plant should be able to operate for 20+ years. It is recommended that components not meeting this criterion be replaced with materials of higher specification or with a more appropriate material.

RECOMMENDATIONS

- The SCADA interface should be made simpler to navigate with critical operational parameters all available on a single front page. Also a clear administrative hierarchy is critical for safety of onsite staff and should be implemented.
- The AWTP be tested for a further 6 months in the absence of personnel performing on-going testing and research and in 'hand-over' mode, whereby the AWTP is operated as it would be at Davis Station. Where possible, remote monitoring of alarms should be instigated to establish the production rates that can be achieved if alarms are attended quickly. In addition, all alarm and alert levels associated with each of the CCP barriers should be fully implemented to simulate fully installed and commissioned operations. The CCP and QCP alert and alarm levels were not established until the end of the trial.
- Additional operation for approximately 6 months is required before deployment at Davis Station to demonstrate the robustness of the chlorine system and to identify more accurate CCP criteria now that the turbidity sensors have been fully calibrated.

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Nomenclature

AAD	Australian Antarctic Division
ADWG	Australian Drinking Water Guidelines
AGWR	Australian Guidelines for Water Recycling
AWTP	Advanced water treatment process
DAWTP	Davis Station advanced water treatment plant
AWRCoE	Australian Water Recycling Centre of Excellence
BAC	Biological activated carbon
BDOC	Biodegradable organic carbon
BNR	Biological nitrogen removal
CCP	Critical control point
DOC	Dissolved organic carbon
HACCP	Hazard analysis and critical control point
HRT	Hydraulic residence time
LRV	Log removal value
MBR	Membrane bioreactor
MF	Microfiltration
PDT	Pressure decay test
QMRA	Quantitative microbial risk assessment
QCP	Quality control point
RO	Reverse osmosis
SCADA	Supervisory control and data acquisition
SPWWTP	Selfs Point wastewater treatment plant
TDS	Total dissolved solids
TMP	Transmembrane pressure
TN	Total nitrogen
TOC	Total organic carbon
TrOC	Trace organic chemical
TSS	Total suspended solids
UV	Ultra-violet disinfection

Introduction

The Davis Station Advanced Water Treatment Plant (AWTP) was designed as a remotely operated advanced water treatment plant. The AWTP has seven functional barriers including ozone (O_3), ceramic microfiltration (MF), biological activated carbon (BAC), reverse osmosis (RO), UV, calcite contactor and chlorination (Cl_2), and when installed at Davis Station will be preceded by a membrane bioreactor (MBR). It was designed to operate on a batch basis to help cater for the water needs of a remote community across variable seasonal usage.

A trail period of investigation (August 2014 to June 2015) was undertaken where the objective was to demonstrate that the AWTP can meet the robustness criteria designated by the Australian Antarctic Division (AAD). These criteria are outlined in Table 1.

Table 1: Robustness criteria for the AWTP.

CRITERIA	COMMENT
Remote operation	The plant should be able to be started and stopped as well as be operated and monitored from a remote location.
Auto start/stop	The AWTP should be able to operate on a batch basis such that it starts and stops automatically in order to satisfy the treatment of the variable wastewater flows from the MBR.
Unskilled local operation	Local operation of the AWTP should be possible using personnel with a good operational knowledge of the AWTP but having qualifications in the plumbing and electrical trades and not expertise in water treatment.
Low risk of non conformant water	Product water from the AWTP should have an extremely low risk of non-conformity to the Australian Guidelines for Water Recycling (AGWR) and wastes from the plant should show an extremely low risk of being harmful to the marine environment.
Low chemical/energy use	The AWTP should be able to operate with a reduced chemical inventory and at an energy cost that is comparable or better than other sources of potable quality water (i.e. desalinated water). The energy use should be significantly better than current AAD operations.
Long plant lifetime	The AWTP should be designed to operate for 20+ years, using piping and componentry that is able to withstand the rigours of transport and saline, chemical and marine environments.

Plant design and operation

Robustness is a concept that means different things to different people and on this basis, how we view 'robust recycling' needs contextualisation. The AWTP was designed as a remotely operated plant for a small community with a variable population. The operational setup, once installed at Davis Station, will be that the feed to the AWTP will be from a buffer tank filled using the effluent from a MBR. The AWTP will then operate at a constant feed rate of 20 L/min. It will start and stop automatically based on level switches on the buffer tank. The population variations across the year means that it will need to operate for up to 21 hours per day during summer with a turn down to an operational status of 4 hours production every two days, during winter. This semi-continuous mode of operation will look to supply recycled water at 70% yield, the remainder being discharged to ocean. The AWTP will enter a standby operational mode in the event that the buffer tank is below a low level criterion and start-up once the tank has reached a high level criterion. The functional design of the plant assumes a pre-determined feed water quality with alarm levels associated with deviation from minimum standards. The source control required to achieve these minimum standards is reported elsewhere [1].

The functional design assumes on-site operational personnel will have good operational knowledge of the AWTP but will not be experts in water treatment or be able to perform tasks requiring a high degree of technical expertise. An example of such expertise might include retuning a SCADA based control circuit. They are expected to have qualifications in the plumbing and/or electrical trades and be able to perform basic maintenance and calibration operations as well as service alarms associated with pump and sensor issues. It is assumed nonetheless, that personnel with a high level of technical expertise will be available for remote consultation and advice, and expert personnel will be available for an annual or bi-annual maintenance event. On this basis, the plant was designed such that it should show low maintenance on a day-to-day basis with annualisation of maintenance events requiring a high level of technical knowledge.

In line with the expectation of maintenance requiring a high level of technical expertise being reduced, the plant was designed to show low filter fouling rates so as to reduce the frequency of rigorous clean in place (CIP) operations requiring highly acid or highly alkaline chemicals. This includes CIP operations for the ceramic micro-filters (MF) and reverse osmosis (RO) filters. To this end, the design included:

- Operation of the MF with a residual ozone concentration to reduce fouling rates of organic contaminants,
- Operation of the MF at a low flux to reduce the incidence of hard to remove fouling layers,
- Operation of a biological activated carbon filter prior to RO to reduce organic loading onto the RO,
- Operation with an in-line cartridge filter that is easy to replace prior to RO to reduce particulate fouling,
- Frequent flushing of the RO membranes with RO permeate when the plant shuts down to reduce the need for anti-scalant,

- Osmotic back-flushing of the RO membranes during shutdown periods to also reduce fouling and scaling, and
- Operation of the RO at lower than maximum recovery rates to reduce scaling and feed pressure.

The chemical inventory required for CIP operations was expected to be lower than equivalent continuous operations elsewhere due to a reduced number of CIP cycles as compared to industry standards. The chemical inventory for chemical additives such as Cl_2 or $CaCO_3$ were expected to be similar to other operational plants since these are dosed per volume of treated water for stability and water safety requirements respectively. In short, the functional design looked to reduce the number of different types of acids and bases, and the number and quantity of cleaning chemicals and CIP procedures.

The plant entered an operational phase in August 2014 after a period of commissioning. The initial phase of operation was to establish remote operations, automatic start/stop operations and adherence to and establishment of pathogen based critical control points. In addition, it was to establish operational calibration criteria for sensors, CIP schedules for the MF and RO and chemical re-fill schedules. Assessment was also made of the level and types of interventions (in technical expertise) required to re-start operations after critical faults. Production was typically limited to a five day per week schedule based on the refill cycle of a 'virtual' buffer tank such that the actual production and standby times were similar. A classical commissioning and hand-over was not conducted and as such, a formal client fault analysis and retribution was also not performed. In addition, some of the analysers and sensors (i.e. turbidity analysers) were not fully commissioned until late in the trial. Rather, an ongoing process of fault improvement was conducted. This was probably not helpful to the ability to fully assess operational robustness since the AWTP was not operated in a mode that simulated actual Davis Station operations. Each week, the on-going experimental and testing plan meant that a particular barrier was being manipulated and instruments were being validated at a higher rate than anticipated under normal operations. In the case of the sensors, this was a deliberate measure to determine minimum maintenance schedules.

In February 2015, a second phase of operations commenced whereby final adjustments were made to the plant and SCADA faults were rectified based on operational knowledge findings of the first 6 months. In addition, a variety of operational modes was programmed, although the most common mode of operation was 6.7 hours on and 4 hours standby or off. This equates to 15 hours of operation per day with at least 2 automated stop/starts of the overall plant per day. Trend analysis of operational performance was formally captured on the SCADA for each barrier in the AWTP from March 2015 and fault analysis was recorded in the operator log. The plant was typically shut down for weekends since no personnel were available to monitor alarm status. This is not anticipated as an issue once installed at Davis Station since permanent full-time staff will be dedicated to monitoring station operations, the alarms are displayed on SCADA, and before locating at Davis Station the number of faults causing alarms should be reduced to infrequent events. In addition, the plant was shut down during Easter 2015 and during a period in May 2015 when contaminant concentrations in the feed water far exceeded limits due to maintenance issues at the Selfs Point Wastewater Treatment Plant (SPWWTP). Shut-down also occurred in periods of high flow to SPWWTP due to rainfall, when the feed turbidity to the AWTP was very high. Final configuration of the chlorine detection and monitoring system was not achieved until May 2015. Testing of this barrier was not adequate to make recommendations as to its robustness or resilience.

This report assesses each of the robustness criteria in turn and consolidates the findings of the 10 months of operation. These criteria, taken from those established by AAD, are summarised as remote operation, automatic start/stop, operational interventions to faults, barrier performance, chemical inventory and use, energy use and resilience of components. The criteria are assessed as:

- meeting the AAD criterion,
- meeting the AAD criterion but further changes are recommended, or
- not meeting the AAD criterion.

Robustness analysis and results

Remote operation

The plant is operated through a SCADA interface that is remotely accessible to a range of personnel (both operational and technical) in the project team. All start/stop sequences and operational parameters were controlled through the SCADA interface, except for emergency start/stop buttons and local safety interlocks in the plant. The location of the plant, namely at a TasWater site, with a feed water taken from the wastewater plant discharge prior to UV irradiation and Cl_2 addition, meant that some aspects of the trial operation were not as designed. The most obvious of these was that the water quality, particularly in terms of parameters such as suspended solids, biological oxygen demand (BOD) and dissolved organic carbon (DOC) were higher than would be expected for a feed from a MBR. Ammonia levels were also higher than would be expected of a plant operating biological nitrogen removal (BNR) in association with a MBR, as will be the case once the AWTP is installed at Davis Station. Despite these challenges, the water quality was only outside of the maximum expectations as prescribed in the functional design for short periods during the trial [1]. All sensors associated with feed quality, including turbidity, phosphate and ammonia, were under the control of TasWater and not able to be validated regularly by project personnel. The buffer tank with high and low level AWTP control was absent and replaced by a ‘virtual’ tank in the SCADA system, with virtual fill rate parameters utilised to simulate a range of feed rate scenario’s and operational production times.

The feed water itself was taken from the effluent channel at SPWWTP. It was rough screened (2 mm) and was drawn to the plant by a feedwater pump. This caused a wide range of cavitation and screen blockage issues throughout the trial. As already noted, the lack of an upfront MBR also meant that the water quality was lower than that required by the functional design of the AWTP. In particular, for short periods of time, turbidity was up to two orders of magnitude higher than required, with subsequent effects on ozone consumption and MF fouling rates. Despite these differences, the trial was considered a rigorous test of performance in that nearly all scenarios were more challenging than expected at Davis Station. All other physical aspects of operation, except discharge to an actual potable supply, were as would be expected in a remote operational scenario.

The design of the plant is such that it can only be operated through the SCADA interface. This was possible through a computer interface on-site but remote operation was also instigated from the first day of operations. A number of SCADA updates occurred during the operational period with a major overhaul of faults from February to April 2015. Many of these were associated with operational adjustments and modifications to the plant, including final confirmation of alarm status around a number of barriers as required by critical control point (CCP) operational status. There were a number of emergency shutdown activations during the trial period. These were all associated with high ozone in air concentrations. This alarm status cannot be over-ridden remotely and required local intervention, inclusive of alarm investigation. External venting of the ozone destruction unit was instigated to reduce the number of incidents. These local procedures remain in place as per safety requirements of plant operations and although a repeat of such events are possible once deployed to Davis Station, the AWTP will be operated outside of a containerised environment with a lower probability of ozone build up to concentrations requiring shutdown.

Other reported issues included a lack of an administrative hierarchy in the SCADA that allowed a remotely logged in person to take precedence over local operational personnel. This is a potential safety issue and a SCADA administrative hierarchy needs to be implemented. This was not completed during the trial period because of the large number of remote logins from a range of personnel during the experimental phase but is a key requirement for further operations. In addition, CCP and quality control point (QCP) status and alarm/alert levels were all not available on a simple to read and negotiate front panel. This is considered highly desirable for routine as distinct from experimental operations, as was the case for the trial period.

Remote operation assessment

The assessment of the team for the criterion that the AWTP can be operated remotely is that it is meeting the AAD criterion but further changes are recommended. These changes are mostly cosmetic changes to the SCADA interface, including making it simpler to navigate, with critical operational parameters all available on a single front page. A clear administrative hierarchy is critical for safety of onsite staff.

Automatic start/stop

The AWTP operated through 244 start/stop sequences between September 2014 and mid June 2015. The monthly data is shown in Table 2. As noted previously, the start/stop sequence was based on the filling and then emptying of a virtual tank. The plant entered ‘standby’ once the virtual tank was empty. The plant was shutdown on weekends, holiday periods and when the water feed quality was far ‘dirtier’ than likely in operations where an MBR preceded the AWTP. Operation of the AWTP under these conditions was considered detrimental to the assessment of fouling rates on membranes and validation of the frequency of sensor calibration. The plant was put into an ‘off-line’ status during these shutdown periods.

Table 2: AWTP start/stop sequences in the trial period.

Month	Number
Sept 14	7
Oct 14	43
Nov 14	27
Dec 14	24
Jan 15	11
Feb 15	25
Mar 15	26
Apr 14	49
May 15	22
June 15	10
Total	**244**

An analysis of the most common issues associated with failure to start automatically after entering standby mode showed the predominate issue to be feed pump cavitation associated with either screen blockage or poor line suction. This caused air induction into the feed pipe to the AWTP. This issue was considered to be external to automatic start/stop robustness assessment since the design configuration for the AWTP is that the feed has a positive head pressure and is from a buffer tank that collects the MBR effluent. The likelihood of screen blockage and cavitation is considered low in proposed the Davis Station configuration.

The main issues that caused the plant to go into standby as a result of a fault (more than once) where associated with incomplete valve closure, ozone safety interlocks, cavitation of the discharge pump from the AWTP and errors in the SCADA logic in standby mode that caused the plant not to re-start automatically. As an example, a number of issues arose whereby the plant went into fault on going into standby and these faults required rectification prior to start-up. If these occurred on a weekend, the issue was often not rectified until Monday morning or when an operator came on site for weekly testing. This reduced the theoretical water production rate, although this was not a focus during the trial period. In the case of errors in the SCADA system or incomplete valve closure, re-programming was required and the intervention was considered not able to be fixed by standard operational personnel. In most cases, these faults could be rectified remotely by those with a high level of SCADA expertise. Indeed, analysis suggests that very few faults (<10) could not have been rectified remotely. Despite this consideration, a number of the faults were often dealt with locally since an operator was on-site.

During the last three months of operation (April-June 2015), the plant demonstrated that it could start and stop reliably and without the need for operator intervention. There were a number of issues that required intervention by personnel with a high level of expertise but these were not associated with the automated start/stop functionality. An assessment of all faults for the period is provided in a later section (Table 5).

Automatic start/stop assessment

The assessment of the team is that the AWTP is meeting the AAD criterion of automatic start/stop.

Operational interventions

A key value assessment of the robustness of the plant is an ability to operate without the need for high-level technical assistance on-site. A range of faults on the plant, nominally left over from commissioning, required expert intervention in the first six months of operation. In the period from March 2015 to June 2015, there were changes still being made to the plant, including installation of the chlorine sensors in the chlorine barrier and an autopsy on one of the RO membranes. However, many of the 'commissioning' style faults identified in a February 2015 audit had been fixed and the plant was able to operate closer to a fully commissioned state. An overview of the operational status of each of the barriers is shown in Table 3 for the final three months of operation in the trial period. The status of the plant is defined as follows:

Out of Service: The plant was out of service due to poor water feed quality, maintenance, holidays or weekends.

On-line: The plant was available for water production. This includes periods of actual water production and periods where the plant was in 'standby' but available for production.

Faulted: There was a fault on the plant that made it unavailable for production.

In terms of production on the plant, the parameters used to determine outputs were:

Cycles expected: Theoretical maximum number of cycles based on percentage of time the plant was 'on-line'.

Cycles actual: Number of cycles actually completed based on automatic start/stop of the plant.

Production: The percentage of production for the time period based on the actual versus theoretical number of cycles.

Table 3: Monitored performance based on SCADA flags for the AWTP across the final three months of the trial period (April to mid June 2015) inclusive of the number of production cycles (from Table 2). The % faulted time is representative of the online time that the plant was in fault.

Status/Month	April	May	June
% Out of Service	16.28	29.49	0.50
% Online	83.71	70.50	99.52
% Faulted	14.47	20.42	38.16
Cycles expected	56	47	22
Cycles actual	49	22	10
% Production	87.5	46.8	45.5

The production rates reflect that faults that occurred outside of the Monday-Friday time period were not dealt with until an operator was next on site. An analysis of whether many of these could have been fixed through remote intervention is now considered. The types of interventions on the plant are designated as follows:

External: The cause of the shutdown was due to an external factor or component that will not be present when the plant is deployed at Davis Station, e.g. feed pump cavitation.

Internal: The cause of the shutdown was a plant related factor that would be expected to also cause an issue if deployed at Davis Station, e.g. incomplete valve closure.

The internal category has been further categorised as:

Remote: The shutdown issue was fixed or could have been fixed through remote logon.

Local (technical): In the opinion of the operational personnel, resolution of the issue would require an advanced technical understanding of the plant.

Local (non-technical): The issue could have been resolved by a well-trained operational person with a plumbing or electrical trade qualification.

As of mid June 2015, the plant had processed 2.2 ML of water during the trail period. The operational expectation for a full year of operation when installed at Davis Station was that the plant process 4 ML of feed. The production rate across the trail period was therefore at just over 60% of the final operational requirement. The final three months of operation also showed a production rate that was lower than that required once installed at Davis Station. The issue was the nature of the faults that caused the plant to be in non-production mode and the level of intervention required to fix the issue. Fault logs for each of the barriers is shown in Table 4, although some of these faults for an individual barrier were not of a type to cause the plant to be 'faulted' and stop production. However, all faults in the 'overall' system caused the plant to go into 'faulted' mode whereby water production was not possible.

Table 4: Percentage of time each of the barriers was in fault across the last three months of the trial period (April to mid June 2015).

Month	Ozone	MF	BAC	RO	UV	Cl_2
April	2.9	11.6	2.7	19.6	0.0	6.4
May	0.2	7.4	0.2	0.2	0.0	12.4
June	0.00	19.3	0.0	0.0	2.8	11.7

A first look at the data in Table 4 would suggest that the MF, RO and Cl_2 barriers were the main cause of faults and poor production. However, it is the assessment of the nature of the faults (not just the time faulted) that determines whether they were genuinely contributing to a poor robustness and low water production of the plant under the interventions criteria. As noted earlier, many trivial faults were left until an operator was next on-site rather than being fixed immediately since production rate was not a critical criteria during the trial period and no personnel were available to rectify faults for up to three days per week.

The operator log was examined in detail for each barrier and the faults allocated a designation of 1 (external) or 2 (internal). The second category was further designated as 2a (remote), 2b (local technical) or 2c (local non-technical) whereby 'remote' indicates that the fault was able to be fixed remotely, 'local technical' indicates that personnel with a high level of technical expertise was required to fix the fault and 'local non-technical' indicates that normal operational personnel were able to fix the fault.

Table 5: Detailed faults analysis on AWTP fro the final three months of operation of the trial period (April to June 2015).

Barrier	Month	Fault designation	Description
Feed	April	1	Low flow due to feed screen blockage. Solution: Clean screen, bleed feed line, reset fault and start plant.
Feed	May	1	Low flow due to feed screen blockage. Solution: Clean screen, bleed feed line, reset fault and start plant.
Feed	June	1	Low flow due to feed screen blockage. Solution: Clean screen, bleed feed line, reset fault and start plant.
Ozone	May	2c	Ozone generator L3042 overloaded. Auto control not enabled. Solution: Auto controlled enabled and system reset.
Ozone	May	2c	Power fail on the ozone generator caused shutdown. Solution: Ozone generator reset.
Ozone	April	2c	Ozone generator L3042 "overload" fault due to failed cooling water pump. Solution: pump replaced
Ozone	May	1	System in fault due to ozone flow rate monitoring for ozone dose calculation check.
MF	March	2c	No. 2 MF Feed-in Valve (L3059) not available. Solution: Air filter on valve for air system broken in BAC section. Replaced valve.
MF	March	2b	"MF 1 failed PDT" fault would not clear and hence could not start plant. Solution: Sticking valve due to contamination but hard to identify. Resolved valve non-closure and changed SCADA to include leak test on valve as well as membrane.
MF	March	2a	CEB for MF waiting for operator to approve the conductivity and pH. There is an issue with the pH value in the recipe. Solution: pH range modified in SCADA.

Barrier	Month	Fault designation	Description
MF	April	2c	MF system fault due to requested CEB and CIP system awaiting operator approval of pH/conductivity deviations. Problem caused by air lock in hypo dosing line. Solution: Air bleed installed in line.
MF	May	2a	MF sequence fault. Waiting for operator approval of pH/conductivity deviations. Problem caused by air lock in hypo dosing line. Solution: Hypo dosing pump sequence changed to remove air lock.
MF	June	2c	MF Feed-in Valve (L3059) not available. Solution: Loss of air pressure due to valve failure. Replaced valve.
BAC	April		No faults that caused plant to go to faulted status.
RO	April	2a	RO valve L3119 (failed to open), actuates manually, but won't reset on SCADA. Solution: SCADA adjustment.
RO	April	2c	RO permeate conductivity array physical display in fault. Solution: Display was unplugged, plugged back in.
UV	June		No faults that caused the system to go to standby.
Cl_2	April	2a	Chlorination section closed down due to both tanks full. Logic issue in the SCADA. Solution: SCADA logic rectified.
Cl_2	April	2a	Chlorination dosing pump fault (L3248) caused by installation of bleed line. Solution: Fault reset on SCADA.
Cl_2	May	2a	Chlorination CCP alarm limit not being achieved in newly installed system due to fault in logic circuit. Solution: revise logic in SCADA.
Cl_2	May	2c	Shutdown fault due to product water valve passing water and emptying the chlorine contact tank. Solution: Manually adjusted the valve.
Cl_2	June	2a	Shutdown fault due to chlorine dosing Solution: Adjusted SCADA logic for circuit.

Based on the detailed log in Table 4, of the 19 faults that caused the AWTP to be faulted and require intervention to restart in the three month period, 4 were designated external, 6 were designated as type 2a (able to be fixed remotely), 1 was designated 2b (requiring local intervention of personnel with an advanced technical understanding of the plant) and 8 were designated as 2c (able to be fixed by normal operational personnel). Nearly all of the 2a faults were SCADA related issues that have now been rectified, many associated with tuning of the newly installed chlorine circuit. Ozone faults were caused by the 'slow' failure of a cooling water pump. The fault that required expert on-site assistance was associated with the MF circuit and an ability to determine the cause of a leak in the PDT circuit. The SCADA logic has been changed to make isolation of such issues easier in the future. Many of the faults that were not related to commissioning of the SCADA or a particular barrier were valve related.

A summary of each of the barriers shows:

Ozone: After initial start-up issues on the ozone generator and ozone monitors in August 2014, the ozone barrier performed without serious faults or issues until a failed water cooling pump in April/May 2015. There were no other issues.

Ceramic MF: This barrier was robust to any membrane failures and showed good flux recovery and low fouling rates in the presence of residual ozone. All fault issues were associated with a series of valve issues and logic issues in the SCADA. The PLC logic around chemical enhanced backwashing caused on-going issues until the end of April 2015.

BAC: This barrier caused no issues other than carry over of fine carbon to the RO system. This carbon was captured in a pre-filtration filter that required regular changes (approximately every two weeks). The cost of these filters is low. It took many months to determine the correct backpressure build up rates and filter replacement rates to ensure that this pre-filtration system did not cause plant shutdowns.

RO: This barrier operated very effectively in terms of ionic and molecular rejection with only two chemical cleaning cycles in the term of the trial. It was originally hoped that the plant could operate for at least 12 or six months without the need for chemical cleaning so as to reduce the chemical inventory for this task. Autopsy of one RO unit showed contamination was predominately organic and likely associated with the high BDOC in the RO feed. Extending the empty bed contact time of the BAC would likely reduce the BDOC in the feed to the RO and further reduce biofouling. This is not available to the current design but future design should consider this option. There were a number of valve issues associated with the permeate tank requiring valve closure control.

UV: There were no issues with the UV unit for the entire trial. There were no lamp failures and despite the large number of stop/starts, no obvious increase in the expected decay rate of lamp output intensity relative to a continuously operated system.

Calcite: No issues other than awkwardness in re-filling the vessel. The rate of calcite consumption was in-line with the functional design.

Chlorine: The commissioning of the chlorine sensor units associated with this barrier was not finalised until May 2015. This was predominately due to slow parts supply. Tuning of this circuit was not completed until late May 2015 and as such, this circuit was not evaluated over an extended period.

Operator intervention assessment

The assessment of the team is that the AWTP is not meeting the AAD criterion for operation without the need for expert personnel on site. However, the likelihood is that the AWTP can meet the criterion if the trial is extended since all barriers on the plant were not fully commissioned until the end of May 2015. In the last three months of operation, only one intervention required expertise consistent with an advanced understanding of the plant. Although encouraging, operation of the AWTP at high production rates and in an operational mode consistent with the final installation would be needed to achieve a positive outcome to this criterion. It is recommended that the AWTP is tested for a further 6 months in the absence of personnel performing on-going testing and research and in ‘hand-over’ mode, whereby the AWTP is operated as it would be at Davis Station.

Where possible, remote monitoring of alarms should be instigated to establish the production rates that can be achieved if alarms are attended quickly. This was not always the case during the trial where alarms were often only attended once an operational person arrived at site, although many could have been attended remotely. AAD are planning and budgeting for continued operation at SPWWTP. In addition, all alarm and alert levels associated with each of the CCP barriers should be fully implemented to simulate fully installed and commissioned operations. QCP alert and alarm levels were not established until the end of the trial. In addition to the operational intervention overview, an assessment was made of the ease of calibration and validation of all instruments and sensors on the AWTP. This assessment is shown in Appendix 1.

Barrier performance

The assessment of the risk associated with the AWTP supplying a product water that conforms to the Australian Guidelines for Water Recycle is assessed in three reports associated with this project [1-3]. An additional assessment is made of the risk that the discharge from the plant will have minimal effect on the environment. The assessment includes the criteria for the operation of CCP and QCP barriers. It is concluded, based on the data in these reports that the AWTP is able to meet this water quality criteria, namely that with adequate source control, it will be able to easily meet this criterion for both pathogens and chemicals of concern. This is based on operational data from SPWWTP where spikes in pathogen and chemical inputs are less likely than in a small community. Despite this observation, it is concluded that the AWTP is able to supply water that meets the criterion as stated. It is likely given the remote deployment of the AWTP, that it will require development of a cheap and disposable on-site test for water quality in terms of chemicals of concern without the need to resort to costly laboratory assessment.

Chemical use

A number of chemicals are used within the AWTP for normal operations. Two of these, namely calcite for water stabilisation and sodium hypochlorite for residual Cl_2 levels in the final barrier product water, will both be used at rates consistent with any other water production plant such as for desalination. The inventory for these chemicals is easily calculated as a multiplier of either the residual levels in the product water for calcite or the dosed amounts for hypochlorite, multiplied by the expected volume output of 2.8 ML per annum (based on a 70% production rate of water for a 4 ML per annum feed).

The use of chemicals for membrane CIP is the main area where it was envisaged that the AWTP would allow a reduced chemical inventory. The choice of ceramic MF was made such that chemical enhanced backwash with hypochlorite would reduce the need for more complex chemical backwash formulations and reduced CIP events. It also allows for a single chemical to be used for final product water chlorination and regular membrane cleaning. The flux recovery in the ceramic MF using hypochlorite in each backwash and sulphuric acid after every 15 backwashes proved successful in flux recovery across the trial period. It is possible that the use of sulphuric acid could be further reduced. This is a favourable scenario relative to micro/ultra-filtration plants using polymeric membranes operating on secondary wastewater effluent as a feed where CIP cleaning is expected every 300-450 hours of filtration operation.

The use of ozone, MF and BAC prior to RO and operating the RO barrier at 70% recovery along with backwashing the RO membrane with permeate was designed to reduce the number of CIP events for the RO membranes. This also proved successful, although it did not eliminate the need for RO CIP and two cleaning events were required in the trial period. This represents a total CIP chemical inventory of less than 5 kg per year. Comparison to a large-scale water reclamation plant using RO, CIP cleaning was typically expected every 300-450 hours of filter operation. This would equate to monthly CIP operations based on production rates in the AWTP. The CIP requirement is thus of order one fifth of a conventional plant.

In addition, SMBS was used for RO membrane preservation. The shutdown periods in the trial were far more frequent and for a longer duration than expected during final deployment. As such, the actual SMBS usage is expected to be significantly lower than in the trial. The main chemical inventory is therefore calcite, hypochlorite, SMBS and sulphuric acid with the total chemical inventory shown in Table 6.

Table 6: Estimated use of chemicals for the AWTP.

Chemical	Use	Use rate/4 ML
H_2SO_4 10%	MF backwash	40 L
NaClO 10-15%	MF backwash	40 L
NaClO 8-12%	Product Water	300 L
Calcite	Water stabilisation	160 kg
NaOH 40%	RO CIP	4 L
EDTA	RO CIP	1.0 kg
Na_2SO_4	RO CIP	1.0 kg
Citric acid	RO CIP	1.0 kg
SMBS	Membrane preservation	40 kg

Chemical use assessment

The assessment of the team is that the AWTP is able to operate with a reduced chemical inventory due to the ozone residual on the ceramic MF, the regular use of permeate to backwash the RO, the lower than maximum recoveries on the RO and the lower than maximum flux on the ceramic MF, all of which reduce fouling rates. As a result, the chemical inventory for CIP cleaning and backwashing the MF is reduced to hypochlorite and sulphuric acid. The assessment is that, in terms of operating with a reduced chemical inventory, particularly in the area of CIP, the AWTP is meeting the criterion.

The data in Table 6 is the estimated stock to operate the plant for one year (assuming the processing of 4 ML of feedwater). The total mass of chemicals to operate the plant for one year is approximately 600 kg.

Energy use

The energy use of the AWTP was assessed in another report [4] and is summarised herein. There is a need to produce 4 ML of potable water for use at Davis Station annually. The energy cost of current operations is unknown but it approximated as 108 kWh m^{-3}. This is made up of a combination of diesel fuel used for direct heating of water collected from a hyper-saline tarn and diesel fuel to generate electricity that is then used to run pumps for desalination. The estimated diesel use is of order 50,000 L per annum. Operation of the AWTP and use of the product water for potable augmentation would produce 2.8 ML of water per year at an estimated energy cost of 1.9 kWh m^{-3}. The estimated overall saving in diesel utilisation is 33,000 L. Further analysis of the AWTP, should it be configured at a scale of 5 ML per day, indicates a likely energy utilisation of order 1.3 kWh m^{-3}. This is significantly lower than desalination. The assessment is that in terms of operating with a reduced energy use, the AWTP is meeting the criterion.

Resilience of instruments and fixtures

A summary of the performance of each of the instruments and fixtures of the AWTP is shown in Appendix 1. Initial choice of sensors and meters based on performance reviews from our commercial partners proved useful in achieving good reliability across the AWTP. There were, however, three items that proved to be problematic. These include:

- ***Turbidity meters:*** These proved to be very sensitive to the quality of the feed and it proved difficult to achieve good data reproducibility across a range of operating conditions. Once set up and calibrated correctly towards the end of the trial period, they operated well for the limited time available. Further testing of these meters (of order 6 months) is required to confirm reliability.
- ***Chlorine sensors (Wallace & Tiernan):*** Spare parts for these units were slow to be supplied. This tardiness compromised the ability of the team to assess the robustness of the chlorine barrier. In addition, the spares inventory is extensive. Further testing of these meters (of the order of 6 months) is required to confirm reliability.

- ***Static mixer:*** All components in contact with full strength hypochlorite, including static mixers, showed excessive corrosion and failure. Replacement in plastic is recommended. The static mixer and pipework downstream of the hypochlorite dosing point are being changed to plastic. There are a number of un-passivated welds in the barriers post RO that are unlikely to show the corrosion resistance required for 20+ years of operation.
- ***CIP makeup area:*** The sink and supporting structures showed failure after six months of operation and need replacement with more resilient materials.

Resilience assessment

The data from the table in Appendix 1 shows that the maintenance and calibration of instruments, including the required tolerances, all represent an operational scenario that meets the resilience criterion required by the AAD. It is recommended none-the-less that the turbidity analysers and chlorine system be tested for an additional trial period of at least 6 months. There are a number of fixtures in the plant that are considered by the team to be inadequate and unlikely to show a long service life. On this basis, the AWTP is considered to not be meeting the resilience criterion and modification of the highlighted items is recommended prior to installation at Davis Station.

Conclusions

The robustness and resilience of the AWTP was assessed against the criteria put forward by the AAD. Table 7 shows a summary of the assessment. The assessment was in three categories, namely:

- meeting the AAD criterion;
- meeting the AAD criterion but further changes are recommended; or
- not meeting the AAD criterion.

Table 7: Robustness and resilience criteria for the AWTP.

CRITERIA	ASSESSMENT
Remote operation	Meeting the AAD criterion but further changes are recommended.
Auto start/stop	Meeting the AAD criterion.
Unskilled local operation	Not meeting the AAD criterion.
Low risk of non conformant water	Meeting the AAD criterion.
Low chemical/energy use	Meeting the AAD criterion.
Long plant lifetime	Not meeting the AAD criterion.

Recommendations

- The SCADA interface should be made simpler to navigate with critical operational parameters all available on a single front page. Also a clear administrative hierarchy is critical for safety of onsite staff and should be implemented.
- The AWTP be tested for a further 6 months in the absence of personnel performing on-going testing and research and in 'hand-over' mode, whereby the AWTP is operated as it would be at Davis Station. Where possible, remote monitoring of alarms should be instigated to establish the production rates that can be achieved if alarms are attended quickly. In addition, all alarm and alert levels associated with each of the CCP barriers should be fully implemented to simulate fully installed and commissioned operations. The CCP and QCP alert and alarm levels were not established until the end of the trial.
- Additional operation for approximately 6 months is required before deployment at Davis Station to demonstrate the robustness of the chlorine system and to identify more accurate CCP criteria now that the turbidity sensors have been fully calibrated.

References

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4. Scales, P., A. Knight, S. Gray, J. Zhang, M. Packer, and K. Northcott, *Energy use and comparison*. 2015, Demonstration of robust water recycling (Project number 3170), Australian Water Recycling Centre of Excellence, ISBN 978-1-922202-52-9.

Appendix 1

Plant sensor reliability overview on a scale of 1-10 where 1= poor, 5=fair, 7 = good, 8=very good, 9=excellent, 10 = outstanding. Two criteria were considered, namely the ease of regular maintenance of the instruments and the ease of calibration of the instruments. Items that scored a 5 or less on any of the criteria that could not be dealt with by annualised maintenance or calibration using personnel with a high level of technical knowledge were considered unsuitable and unlikely to be resilient to long term operations. None of the instruments fell into this category.

Barrier	Component	Maintenance	Calibration	Calibration Frequency	Absolute Verification Tolerance	Comment
Feed	Flowrate	9	8	Yearly	N/A	Very reliable instruments and can be verified/recalibrated with a bucket and stop watch.
Ozone	Ozone liquid residual sensor	8	5	Yearly	±0.1 mg/L	No calibration or adjustment in nine months; instrument was verified weekly. Very large variation in a short period and hard to achieve a stable reading during verification.
	Ozone gas phase concentration sensor	8	3	Yearly	N/A	Recalibration of the BNC sensor is recommended in the factory every 2 years.
	Gas flowrate meters	8	5	Yearly	N/A	Currently a manual rotameter but it will be replaced by a on-line meter to give a 4-20 mA signal.
	Feed temperature	9	5	Yearly*	N/A	Temperature sensors sold with no drift claim; a yearly check is all that is required
Ceramic MF	Ozone liquid residual sensor	8	5	Yearly	±0.02 mg/L	No calibration or adjustment in nine months. Instrument was verified weekly.
	Turbidity meter	7	8	Monthly	±0.02 NTU	Meter is reliable but can be easily affected by dissolved air. The meter was adjusted at least once a month. The sample pump failed quite a few times until replacement with a new pump type. These may need regular replacement.
	PDT pressure sensor	9	4	Yearly*	N/A	Pressure sensors sold with no drift claim; a yearly check is all that is required.

Barrier	Component	Maintenance	Calibration	Calibration Frequency	Absolute Verification Tolerance	Comment
BAC	Turbidity meter	7	8	Monthly	±0.02 NTU	Meter is reliable but can be easily affected by the dissolved air bubble. The meter was adjusted at least once a month. The sample pump failed quite a few times
	BAC Level Sensor	9	4	Yearly*	N/A	Pressure sensor used for level measurement is sold with no drift claim; a yearly check is all that is required.
RO	Conductivity meters	8	8	Three monthly	Permeate: ±2 μScm^{-1} Concentrate: ± 150 μScm^{-1}	Meters are very reliable.
	PDT pressure sensor	9	4	Yearly*	N/A	Pressure sensor sold with no drift claim; a yearly check is all that is required.
	Combined permeate flow meter	9	8	Yearly	N/A	Very reliable instrument and can be verified/recalibrated with a bucket and stop watch.
UV	UV intensity Sensor	9	1	Yearly	N/A	Yearly check recommended by supplier using calibrated UV sensor. Recalibrated at the factory if required.
$CaCO_3$ contact	Hand held conductivity meter	9	8	Before measurement	±190 μScm^{-1}	The conductivity needs to be checked every three months, to identify if the conductivity is less than 100 μScm^{-1}. Standard: 1990 μScm^{-1}
Chlorination	pH	6	8	Weekly	±0.5	Drifts quite often. Might be due to $CaCO_3$ precipitation
	Chlorine residual meters	6	4	Weekly	±0.1 mg/L	Weekly adjustments
	Level Sensors	8	8	Yearly*	N/A	Pressure sensors used for level sensing sold with no drift claim; a yearly check is all that is required.

*Temperature and pressure sensors, including level sensors, have no defined calibration frequency. Yearly checks on calibration are recommended here.