Australian Water Recycling
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Demonstration of Robust Water Recycling: Experimental Plan

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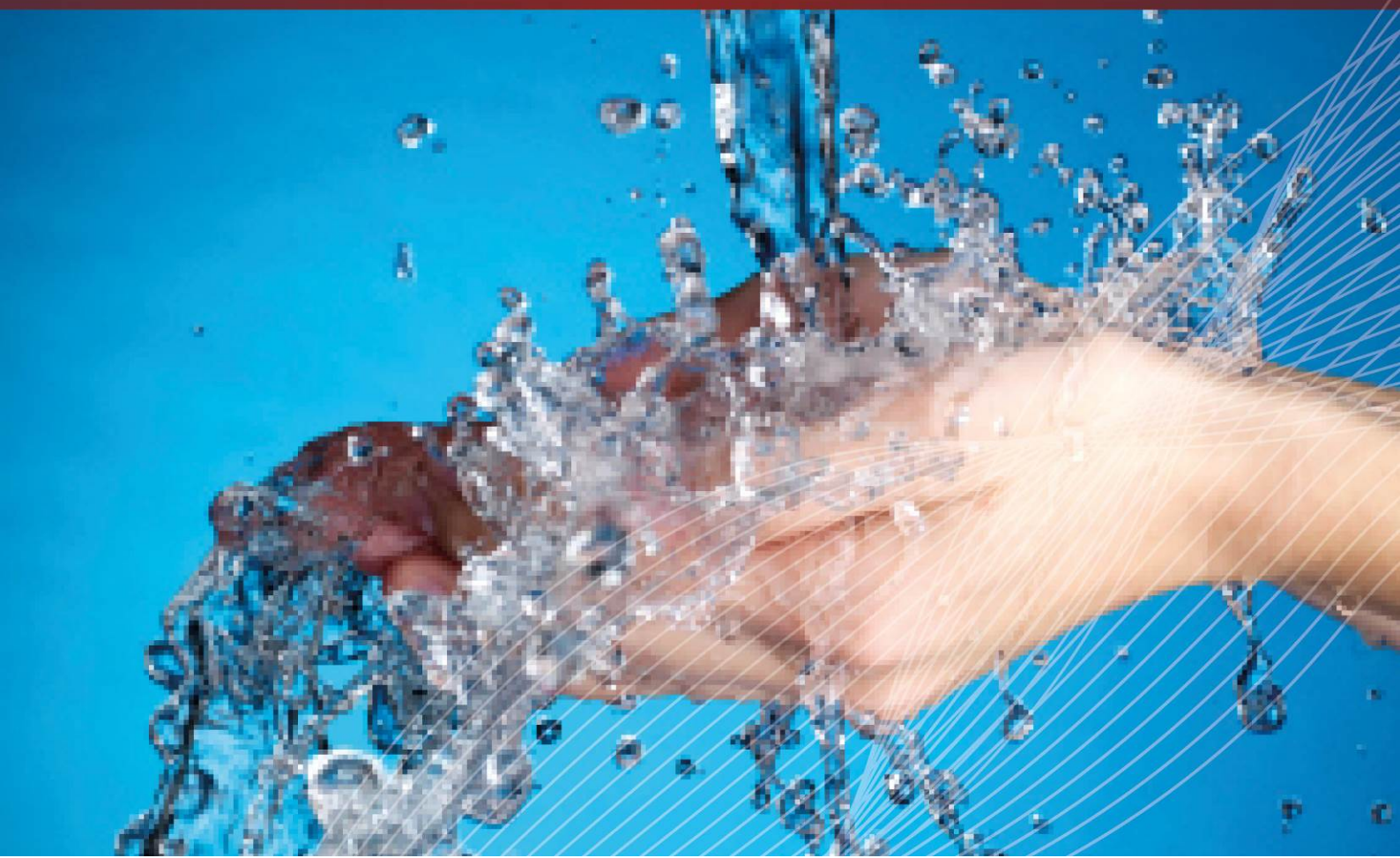

Demonstration of Robust Water Recycling: Experimental Plan

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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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1. Introduction

1.1. Purpose of Demonstration

The Davis Station Advanced Water Treatment Plant will undergo demonstration operation in TasWater's Selfs Point site prior to integration into David Station. The Demonstration Plant includes the unit processes of ozonation, microfiltration via ceramic membranes (CM), biological activated carbon filtration (BAC), reverse osmosis (RO), UV disinfection (UVD), calcite filtration for water stabilisation and chlorination. The purpose of the demonstration is to assess the suitability of the technology, determine standard operating control points and to validate barriers as required by a Health Regulator (HR). Due to the nature of the final site a relevant HR is still being determined at the time of writing.

Due to its final location in Antarctica, the Demonstration Plant is designed to be operated remotely with minimal intervention. While wastewater inflows will be highly variable, the Advanced Water Treatment Plant will be feed at a constant flowrate from a feed tank. Operation will be intermittent and will vary between continuous operation during summer months and operation for 4 hours every 2 days during winter. The robustness of the plant in this respect will need to be assessed along with maintenance requirements, in particular the maintenance of membranes (CM and RO), operation of BAC and calibration and maintenance of all sensors.

1.2. Demonstration Testing Objectives

The two primary objectives of the demonstration plant are to:

1. Determine the robustness of the treatment process and the suitability of remote operation of the plant.
2. Determine the routine operational set points for remote access, to confirm alarm triggers and identify intervention strategies for the plant when in place in Antarctica.
3. Provide information to the HR on the operation of the plant with regards to important health parameters including pathogens and Trace Organic Compounds (TrOCs).

The data generated will be used to help attain HR validation in terms of log reduction values (LRVs) for pathogens and ensuring trace and bulk chemical requirements are met, both in the product and discharge waters. Table 1 contains a list of chemical requirements for the plant, while Table 2 shows the attainable and claimed LRVs for each barrier.

Table 1: Final product water quality requirement of Davis Advanced Wastewater Treatment Plant.

Parameter	Minimum Value	Maximum Value	Units
Turbidity		0.05	NTU
pH	6	8	
Chlorine Residual	0.05		mg/L
Alkalinity	40		mg/L as $CaCO_3$
Total Dissolved Solids		500	mg/L
Iron		0.05	mg/L
Manganese		0.02	mg/L
Aluminium		0.1	mg/L
Ammonia		0.1	mg/L
Bromate		0.02	mg/L
Colour		5	HU
Taste and Odour		Acceptable	
Total Coliforms		<1	counts/100mL
E coli		<1	counts/100mL
Trihalomethane		0.2	mg/L

Table 2: LRV requirements for the plant and the achievable and claimed LRV's across individual barriers.

Barrier	Pathogen	LRV Required	
Whole Plant	Viruses	13	
	Bacteria	13	
	Protozoa	10.5	
		LRV Attainable	LRV Claimed
Barrier 1 - Ozonation	Viruses	> 4	4
	Bacteria	> 4	4
	Protozoa	> 2	0.5
Barrier 2 - CM	Viruses	> 4	0
	Bacteria	> 4	0
	Protozoa	> 4	4
Barrier 4 - RO	Viruses	> 4	1
	Bacteria	> 4	1
	Protozoa	> 4	2
Barrier 5 - UVD	Viruses	> 4	4
	Bacteria	> 4	4
	Protozoa	> 4	4
Barrier 6 - Chlorination	Viruses	> 4	4

	Bacteria	> 4	4
	Protozoa	0	0

Note: The MBR system is used prior to the current plant and will provide 2 LRV. It is not tested as part of this system. Barrier 3 (BAC) provides no LRV credits.

Within this, a series of secondary objectives have been developed to assist in identifying how the process is performing and ways in which the process may be further optimized in future work to reduce the operating costs inherent in the system and ensure that discharges from the plant are of the highest environmental standards. These secondary objectives will both confirm design criteria obtained in concurrent laboratory trials and establish benchmarks in this area, particularly with respect to:

1. Providing information as to the environmental safety of discharge from the plant.
2. Providing an overview of total energy use per m^3 of water produced.

The main focus within these objectives would be on Point 2, as this is the key to the process in terms of operation in the absence of a potable water output.

The main metric to be used in the test, therefore, is to relate the generation of ozone to the reduction of organics and production of bromate in the water, and the bio-analytical effect of the discharged water. Particular attention will need to be paid to potential catalytic effects imparted by the CM. This has led to the development of two metrics:

- Mass of organics reduced/(mass of ozone.pre-membrane contact time)
- Mass of bromate produce/(mass of ozone.pre-membrane contact time)

This information can be obtained for a given ozone dose by measuring a series of parameters including:

- 5-day biological oxygen demand (BOD_5)
- Chemical oxygen demand (COD)
- Total organic carbon (TOC)
- Trace organic compounds (TrOCs)
- UV absorbance at 254 and 210 nm (UV-254 and UV-210).
- Yeast-based recombinant receptor-reporter gene bioassays

This data would extend upon the existing laboratory work based at Victoria University.

1.3. Structure of Report & Reference Documents

This report will detail the important design parameters and requirements of the plant in Section 2. Section 3 will be dedicated to the routines processes and operational settings required during the proposed demonstration. Section 4 provides information on analysis and reporting. This section focuses on the testing requirements on-site and the sampling requirements for the University of Melbourne, Victoria University and TasWater. While some information will be provided on the general testing procedures at the University of Melbourne and Victoria University, this document will not provide detailed descriptions of analytical techniques. Readers should refer any questions related to analysis to those responsible for performing the tests. The final section of the report is dedicated to QA/QC for the project, particularly with regards to sampling and analysis, both on site and off site.

1.4. Reference Documents

This Experimental Plan should be read in conjunction with:

- Davis Station Advance Treatment Plant P&ID (Drawing number 27/13/07)
- Davis Advanced Water Treatment Plant Functional Description (Document Number to be issued).

2. Materials & Methods

2.1 Plant Location

The plant will be operated at the TasWater Selfs Point Wastewater Treatment Plant (SPWWTP) in New Town, Tasmania. The plant will be located next to the trickle filters on the site. A site map with the location of the plant is shown in Appendix A.

2.1.1 Feed Water Source

The plant will operate on secondary effluent drawn from the UV channel just prior to UV disinfection. The water has undergone secondary treatment and clarification. It will be of similar quality to the water expected at Davis Station, however it will not undergo filtration. The intake to the plant will be fitted with a screen that is able to be backwashed, removing some of the larger materials present in the water.

2.1.2 Feed Water Quality

Table 3 contains the water quality parameters for tertiary effluent from the SPWWTP. It should be noted that this water quality has been determined after tertiary treatment. There is a need to determine baseline data as part of the project, and monitoring on a routine basis. This monitoring will be provided by TasWater, Victoria University and University of Melbourne. TasWater are able to provide on-line analysis of ammonia, nitrate, phosphate and turbidity. Baseline of a range of parameters will be obtained using an autosampler with hourly sampling occurring over the period of one to two weeks. These samples will be analysed at Victoria University and University of Melbourne as outlined in Section 3.1.1.1. Subsequent monitoring will be based on a regular (monthly) sampling regime (see Section 4.3.1).

Table 3: Typical Water Qualities of Selfs Point Wastewater Treatment Plant Tertiary Effluent.

Component	Typical Range	Median
BOD_5 (mg/L)	ND-22	7
N (mg/L)	0.7-33	3
NH_3 (mg/L)	0.2-28.8	0.9
NO_2^-/NO_3^- (mg/L)	ND-8.6	0.3
P (mg/L)	0.3-7.03	2
TSS (mg/L)	ND-43	5.8
pH	6.71-7.76	7.1
Total Cl_2 (mg/L)	0.07-2.2	0.79
Oil and Grease (mg/L)	ND-2.5	1.25

Conductivity (µS/cm)	470-2660	690
Enteroccoci (cfu/100mL)	2-1100	20.5
Thermotolerant Coliforms (cfu/100mL)	<2-7700	72

Note: ND indicates parameter was below detection limits

2.1.3 Plant Capacity

The plant has been sized to treat a maximum flow of 20 L/min or 28.8 kL/day.

2.1.4 Brief Process Description

The demonstration plant consists of six barriers – ozonation, microfiltration through ceramic membranes, biological activated carbon filtration, reverse osmosis, UV disinfection (and calcite buffering) followed by chlorination. More detail on the process including sizing can be found in the Functional Description.

2.1.5 Flow Configuration & Mode of Operation

Information on the flow configuration can be found in the process flow diagram for this system, and is also described in documents *Davis Advanced Water Treatment Plant Functional Design* and *Functional Description* documents.

2.2 Demonstration Plant Base Case Design Parameters

The design parameters for the sizing of the plant and anticipated log removal efficiencies are outlined in the document *Davis Advanced Water Treatment Plant Functional Design*.

2.2.1 Plant Control

Table 4 lists the control points and set points that are available to the plant. Those with default values will not be altered as part of the experimental plan for the plant. They may however be altered during commissioning from the values described here to improve plant performance. Any variation from the values described here must be documented in order to understand any potential impact on ongoing results analysis.

Table 4: Control points and set points available within the demonstration plant.

System	Variable	Type	Default Value
Overall	Feed flow rate	Set Point	20 $L.min^{-1}$
Ozonation	Ozone Circulation Concentration	Control Point	Variable
Ozonation	Ozone Concentration after Contactor	Control Point	Variable
MF	Maximum Transmembrane Pressure	Set Point	2 bar
MF	Maximum Permeate Turbidity	Set Point	0.5 NTU
MF	Pressure Decay Test Decay Time	Set Point	20 s
MF	Pressure Decay Test Maximum Decay Rate	Set Point	0.05 bar/s
MF	Air Scour Time (Backwash)	Set Point	5 s
MF	Soaking Time (Backwash)	Set Point	180 s
BAC	Maximum Headloss	Set Point	75 mbar

BAC	Maximum Turbidity (Triggers Backwash)	Set Point	5 NTU
BAC	Maximum Turbidity (Product Acceptance)	Set Point	3 NTU
BAC	Air Scour Time (Backwash)	Set Point	60 s
BAC	Low Rate Backflush Time	Set Point	60 s
BAC	High Rate Backflush Time	Set Point	60 s
RO	Permeate Flow	Control Point	Variable
RO	Concentrate Flow	Set Point	
RO	Concentrate Conductivity	Control Point	Variable
RO	RO Mix Tank Operational Level	Set Point	75 mbar
UV	Minimum UV intensity	Set Point	50 W/m^2
UV	Minimum Run Time	Set Point	21600 s
CIP	Water Quantity	Set Point	100 L
CIP	Water Source	Set Point	RO Permeate
CIP	Delivery Flow Rate	Set Point	50 L/min
CIP	Circulation Time	Set Point	180 s

Further to this there are operator controls over the following points:

- Length of intermittent plant stoppage
- MF CIP recipe
- RO CIP recipe
- Choice of RO permeate or SMBS for RO storage during dormancy

2.3 Chemical & Utility Requirements

2.3.1 Chemical Requirements

Chemicals can be split into two categories: those required for operating the demonstration plant and those required for sampling and analysis. In terms of plant operation the following chemicals are required:

- Sodium metabisulphite (SMBS) – required for preservation of RO membranes during extended shutdowns. To do this 30 L of a 1 wt% SMBS solution will be required. SMBS will be purchased as a solid and a portion made up to a 6 wt% solution in a 20 L carboy. This will be placed on a dosing line in the CIP room. Due to its limited shelf-life as a solution, it will be replaced once a month. Assuming no more than four preservation events occur in a month, the project will require 21.6 kg of SMBS.
- Sodium hypochlorite – required for disinfection via chlorination and chemically enhanced backwash and CIP of CM. Will be purchased and stored at 8 wt% solutions in 10 to 20 L carboys. One will be attached to a dosing pump and dedicated to the chlorination process. The second will use a separate dosing pump to provide hypochlorite to the CIP tank. The hypochlorite used will not be stabilised and will, therefore, need to be monitored as its activity will decrease rapidly over the course of the project. The free chlorine concentration of the both drums in use should be monitored once a month and dosing requirements changed accordingly. Estimates of worst case suggest that 420 L of hypochlorite will be need for backwashing and CIP and 100 L of hypochlorite for disinfection purposes.

- Sulphuric acid – required for acid backwash and CIP of CM. It will be purchased at 10 wt% solution in 10 to 20 L carboys. It will be attached to a dedicated dosing pump attached to the CIP tank. Sulphuric acid will be diluted to a pH of two (or approximately 0.05 wt%) in the CIP tank before use. Estimates of worst case suggest 105 L of 10 wt% sulphuric acid will be required over the course of the project.
- Hydrochloric acid – required for acid CIP of RO. It will be purchased at 32 wt % in 1 L plastic containers. It will be manually diluted in the CIP tank as required. Assuming only 3 backwashes occur during operation, a maximum of 1 L is required.
- Sodium hydroxide – required for alkali CIP of RO and neutralization of wastewater. It will be purchased as a 40% solution in 5 L plastic containers. It will be manually diluted as required. For CIP a maximum of 1 L would be required over the course of the project.
- EDTA – required for CIP of RO. It will be purchased as a solid and made up manually into solution as required.
- Citric acid – may be required for CIP of RO and CM. It will be purchased as a solid and made up manually into solution as required.
- Sodium sulphate – may be required for CIP of CM. It will be purchases as a solid and made up manually into solution are required.

The chemicals for analytical requirements are:

- Hydrochloric acid – for pH adjustment for true colour measurements.
- N,N-diethyl-p-phenylenediamine (DPD) – for free chlorine measurement used in weekly verification of the three free chlorine detectors. They may also be used for bromine measurements as required. These will be provided as pillow from Hach that will also contain a pH buffer. A minimum of 234 pillows would be required.
- Indigo – for spectrophotometric analysis of residual ozone. It will be used for verification of ozone sensors and as required for other streams.
- Sodium dihydrogen phosphate – for spectrophotometric analysis of residual ozone.
- Phosphoric acid – for spectrophotometric analysis of residual ozone.
- Glycine – for spectrophotometric analysis of residual ozone.
- Malonic acid – for spectrophotometric analysis of residual ozone.

2.3.2 Town Water Requirements

Town water use will be minimised during operation. It will be required at the following points:

- Dilution water at the CIP tank (will routinely use RO permeate from the permeate buffer tank)
- Backwash of the BAC filter
- Feed water to Point of Use GE Merlin RO unit.

Town water does not need to be used at all locations and can be substituted by RO permeate from the plant. However, it will be required for start-up. During the operating period approximately 1.2 kL/month service water will be required for BAC backwash. A total of 25 kL is likely to be needed over the 18-month period.

2.3.3 Demineralized Water Requirements

Demineralized water is required for the flushing of reverse osmosis membranes during commissioning and as a dilution water for preservation. An estimated 1 kL will be required during this stage. During operation demineralized water may be required for sample dilution and/or analysis, rinsing of onsite analytical equipment or preparation of preservation solutions. Victoria University has provided a GE Merlin RO unit for this purpose. It has a production capacity of 2 L/min based on a town water feed of approximately 6 L/min. It is a standard 250V/10A connection. After commissioning a small (20L) storage tanks for demineralized water will be required and could be stored in the chemical container.

2.3.4 Compressed Air Requirements

Compressed air is needed for performing backwashes, air scouring, aeration of BAC and to operate pneumatic valves. In all compressed air will be required at 8 points in the demonstration plant:

- Air flush, scouring, backwashing and pressure decay testing of MF (6 regulators).
- For aeration, scouring and backwash of BAC filter (1 regulator).
- For pressure decay testing of RO elements (1 regulator).

Compressed air will be supplied by the demonstration plant's compressor and external air supply connection is available as required.

2.3.5 Drainage Requirements

The following streams will be need to be directed to drain:

- RO brine – This is a continuous stream that should represent approximately 30% of the plant inflow or 8.64 kL/day. It will contain significant levels of salinity. It is a separate discharge stream.
- CM backwash – This will consist of a maximum of 70 L of water containing low-moderate levels of solids and organics. This backwash is expected to occur no more than once in one hour. It is collected in the drain tank.
- Oxidant CM backwash – This will consist of a maximum of 70 L of water containing <50 mg/L of NaOCl, low levels of solids and low-moderate organics. This backwash is expected to occur no more than once every six hours. It is collected in the drain tank.
- Acid CM backwash – This will consist of a maximum of 70 L of sulphuric acid at an approximate pH of 2. This backwash is expected to occur no more than once every two days. It is collected in the drain tank.
- BAC Backwash – This will consist of a maximum of 1,200 L of water with high levels of solids and organics. It would occur at most once a month. It is collected in the drain tank.

- CM CIP – This will consist of a maximum of 200 L of water that will contain sulphuric acid at pH 2 and a maximum of 200 L of water with <50 mg/L NaOCl. This CIP would occur approximately once every two weeks during the first 3 months of experiments and no more than once every three months during long-term testing. It is collected in the drain tank.
- RO CIP – This will consist of a maximum of 200 L of water containing hydrochloric acid at a pH of 2 to 3 and a maximum of 200 L of water containing sodium hydroxide at a pH of 10 to 10.5. It will occur at most once every six months. It is collected in the drain tank.

As well as these waste streams the water from the following points are directed to the drain tank and ultimately to discharge:

- Overflow from the chlorine contact tanks.
- Overflow from the RO mix tank
- Overflow from the permeate buffer tank
- Overflow from the CIP tank

Further to these traditional waste streams, the product water will be directed to drain for the duration of the demonstration. This will represent 70% of plant flow or approximately 20 kL/day and will contain 0.4 to 1 mg/L of free chlorine.

A waste plan has been developed with TasWater in consultation with the Tasmanian EPA to safely dispose of the wastewater generated. This plan sees all wastewater discharged to the trickle filter at Selfs Point.

3. Experimental plan

3.1 Overview

After wet commissioning the plant will run for 12 months: 6 months under experimental conditions and the remainder months under routine operation. Due to the nature of experiments and current delays on the project, there will be come overlap in terms of commissioning plan under development and this plan.

3.1.1 Overlap with Commissioning Plan

3.1.1.1 Baseline Characteristics of Feedwater

General monitoring for the baseline characteristics of the feedwater will also overlap with this stage of the experimental plan. This will utilize an autosampler that will collect 1 L of feedwater every hour over the course of two weeks. These samples, or subsamples of them, will undergo the basic analyses outlined in Table 5. All analytical methods used will be taken from *Standard Methods for the Examination of Water and Wastewater* or methods derived from these (e.g. Hach colorimetric tests).

These tests will feed in to the monitoring plan that is outlined in Section 3.2. If any of the metals or anions outlined are detected at concentrations greater than those allowed by the Australian Drinking Water Guidelines (ADWG) or the Australian Guidelines for Water Recycling (AGWR) they will be including in the weekly analysis.

It should be noted that while the plant is running, online monitoring of pH of the influent can be provided. Furthermore, TasWater is able to provide online readings for turbidity, nitrate, ammonia and phosphate. TasWater are providing a data link to allow the SCADA to record and track this data. The analysis described for turbidity, nitrate and ammonia described in Table 5 will be performed on 6 randomly selected samples only as a confirmation of this data.

Table 5: Analytical parameters to be monitored in determination of baseline characteristics of feedwater.

Parameter	Method to be Used	Location
Turbidity	Hand-held meter	On-site
APHA Colour	Hach Method 8025	On-site/TasWater
Bromine	DPD Bromine – Hach Method 8016	On site – Samples cannot be preserved.
Particle Size Distribution	TBD based on particle size	University of Melbourne
UV-254		Victoria University
UV-210		Victoria University
Total Organic Carbon	Combustion method – Method 5310 B from *Standard Methods*	Victoria University
Total Nitrogen		Victoria University
Ammonia	Salicylate Method – Hach Method 10031	Victoria University
Nitrate	Chromotopic acid - Hach Method 10020	Victoria University
Nitrite	Ferrous Sulphate – Hach Method 8153	Victoria University
Bromide	Ion Chromatography - Method 4110 from *Standard Methods*	Victoria University
Chloride		
Iodide		
Cyanide	Acid distillation followed by *Hach Method 8027*	Victoria University
Fluoride	Fluoride Ion Electrode - Method 4500-F^-C from *Standard Methods*	Victoria University
Aluminium	ICP – Method 3120A from *Standard Methods*	Victoria University
Antimony		
Arsenic		
Barium		
Beryllium		
Boron		
Cadmium		
Free Chlorine		
Chromium		
Copper		
Iron		
Lead		
Manganese		
Mercury		
Molybdenum		
Nickel		
Selenium		
Silica		
Silver		
Sodium		
Sulphate		
Sulphide		
Tin		
Uranium		
Zinc		

3.1.1.2 BAC Acclimatization and Monitoring

As part of the commissioning process, the BAC filter will need to be established/acclimatised to the feed water and ambient conditions. Due to constraints with the use of established AC from a Veolia-operated plant in Bendigo, fresh AC was added to the plant. This in particular means that the BAC filter will be operating for some period in adsorption mode, interfering with determination of removal of TrOCs and other organic components. The length of this period is unclear but an estimate of 3 to 4 month seems reasonable. While some parts of the experimental plan can be brought forward as they do not rely on the operation of the BAC (validation being one obvious example), monitoring will be performed in order to determine when the BAC is "switching" from adsorption to biological mode. While the BAC is acclimating sampling will be performed twice weekly around the BAC column (SP05 and SP06). These samples will be analysed according to Table 6.

Table 6: Analysis to be performed twice weekly from on samples drawn from SP05 and SP06 to determine BAC performance and operation mode.

Parameter	Method to be Used	Location
APHA Colour	Hach Method 8025 based on Method 2120 B from *Standard Methods*	On-site/TasWater
UV-210		TasWater
UV-254		TasWater
Total Organic Carbon	Combustion method – Method 5310 B from *Standard Methods*	Victoria University
Metals analysis[1]	ICP – Method 3120A from *Standard Methods*	Victoria University

[1] **Specific metals to be analysed will need to be determined by what is present in measureable concentrations in the site feed under the monitoring plan in Section 3.1.1.1.**

3.1.1.3 Quantification of Calcite Dissolution

As one of the final commissioning activities, the rate of calcite dissolution will be determined to confirm the functional design and allow for a prediction of top-up requirements during routine operation. Over the course of four weeks, daily hardness analysis will be performed onsite around the calcite contactor (SP21 and SP22). Hardness analysis will be performed onsite using Hach Test 8030 – a portable colorimeter has been provided to the site for this purpose. Over the four weeks the calcite concentration will be plotted and the average dissolution rate determined.

3.1.2 Experimental Runs

The experimental runs will focus on four areas:

- Online validation
- Ozone dose
- Aeration of BAC during shutdown
- Impact of variable pH

With the exception of validation, the focus will be on determining how the performance of the overall plant varies with particular focus on toxicity of the RO concentrate, TrOCs and

other compounds in the permeate and potential for RO fouling. During these runs, an intermittent stoppage will last for no more than 72 hours and SMBS will be used in preserve the RO membranes during these stoppages.

3.1.2.1 Online validation

Claimed ozonation LRVs of 4 for virus, 4 for bacteria and 0.5 for protozoa are expected based on Ct values from the US EPA LT1ESWTR disinfection Profiling and Benchmarking Technical Guidance Manual. It is recognised that the US EPA guidelines are derived from treatment of surface waters rather than wastewaters, so their use for this application maybe unreliable. Most publications that have studied ozone disinfection of wastewater have had difficulty maintaining a residual ozone concentration, and this may be a limitation that arises in the Davis AWTP. Currently there are no validation guidelines for ozone, although draft guidelines have been presented to the AWRCoE NatVal program by Melbourne Water. We are attempting to have access to these draft guidelines. Indications from Melbourne Water are that if we can demonstrate a 0.5 LRV for *Cryptosporidium* in wastewater then we can assume a 4 LRV for virus and bacteria. They have also indicated that for particle free water we can use E coli as a surrogate for inactivation of virus, but this may need to be re-visited for wastewater containing particles. The Davis wastewater will come from an MBR so particle free water should be guaranteed at the plant's ultimate location, however, at Selfs Point particles are present in the feedwater. It is proposed that verification of the disinfection efficiency for E coli at Selfs Point should be sufficient for virus and bacteria at Davis Station, but acceptance of this approach by the regulatory panel will be required. A hydraulic residence time (HRT) distribution of flow through the unit will be undertaken.

The ceramic microfiltration system from MetaWater has been shown to be capable of achieving 4 LRV for virus and bacteria[1] at 200 $L.m^{-2}.h^{-1}$ on Melbourne Water ETP wastewater (the flux on the Davis AWTP is 50 $L.m^{-2}.h^{-1}$). These results are thought to result in part from the narrow pore size distribution of the 0.1 □m ceran perhaps their greater charge and higher isoelectric point. However, mechanisms for greater removal of bacteriophage via ceramic membranes are yet to be confirmed. These results were achieved on a ceramic membrane that had been previously used in extended pilot plant trials, so should be representative of LRVs achieved in longer term operation. Nevertheless, the work of Dow et. al[1] was not a true validation test and so these LRVs cannot be claimed without further testing. Therefore, only an LRV for protozoa will be claimed (LRV 4). Given the size of protozoa and the size exclusion separation mechanism of the ceramic membrane, we will verify the LRV of 4 using synthetic micron sized particles and particle size distributions following the ceramic membrane. Should validation of ozone disinfection not be possible, then validation of the ceramic MF for bacteria and virus removal may be required although use of turbidity and pressure decay tests for verification of virus rejection may be questionable. The use of a pressure decay test and on-line turbidity for protozoa is appropriate given their larger size.

Biologically activated carbon (BAC) is not used for pathogen removal and so will not be validated. It has turbidity detection on the filtrate to detect breakthrough for control of

1 N. Dow, D. Murphy, J. Clement, M. Duke Outcomes of the Australian ozone/ceramic membrane trial on secondary effluent. Water, 40:6 (Sept), 2013, 45-51

backwashing. Removal of pathogens via a depth filter process is possible but no LRVs will be claimed.

The RO process (5 x BW30 elements) is to claim 1 LRV for virus and bacteria using on-line conductivity. Protozoa will claim 2 LRV based on on-line conductivity and a pressure decay test (PDT). The pressure decay test is based on laboratory experimental testing that demonstrated >2 LRV for micron size particles even when the PDT test failed. The PDT test will be performed for each batch of water treated. On-line conductivity will be used across the 5 elements and across each element to determine if greater LRV might be claimed by the use of more conductivity sensors. Validation of the bacterial and virus rejection will be performed with a challenge test using dyes (eg. Rhodamine WT). Challenge testing for protozoa can be undertaken with micron sized particles.

The UV system is pre-validated to DVGW standards that are not recognised within Australia. Therefore, the UV system will need to be validated via challenge tests according to the Victorian Guidelines for validating treatment processes for pathogen reduction (2013). On-line verification will be achieved by measuring the UV intensity on-line. The measurement is made at the outer surface of the UV reactor and therefore takes into account UV transmissivity and lamp age. A UV intensity of 186 mJ/cm^2 is required to achieve the 4 LRV for virus. The flowrate through the UV system is measured and the HRT distribution will be determined via dye testing.

Chlorine disinfection is to be achieved by dosing of sodium hypochlorite. The required Ct value has been taken from the Victorian Guidelines for validating treatment processes for pathogen reduction (2013). The chlorination system is a batch process with the chlorine dose measured as the dosed feed is delivered to the holding tank. The final chlorine concentration is also confirmed at the end of the holding time using a sensor within the tank. A requirement for challenge testing is not expected given the inability for short circuiting in a batch test. The distribution of chlorine in the holding tank at the end of the holding period is to be check, to ensure there are no areas where the free chlorine concentration is below that measured by the tank sensor.

3.1.2.2 Ozone Dose

For the investigation of TrOC removal efficiencies, toxicity studies of RO brine and the potential for fouling in the RO system, it is important that the system be operating at an equilibrium equivalent to the lowest level of performance. This will only occur where the BAC column has transitioned from operating in adsorption mode to operating only in biological mode. The testing outlined in Section 3.1.1.2 would be used to determine when the removal efficiency of four different organic measurements plateaus. After this is witnessed, experiments looking at variation in the ozone dose can be commenced. Four different doses would be used for one month each. One month is believed to be enough to allow a new equilibrium level to be reached in biological mode. The initial ozone dose will be taken as the minimum required to maintain LRV for protozoa – a residual of approximately 0.4 $mg.L^{-1}$. This will be the operational set point used during BAC acclimatization and therefore the first samples for TrOC analysis may be taken immediately. Three subsequent set points will be chosen based around the results of ongoing laboratory analysis.

Prior to setting a new ozone dose, the demonstration plant will be "reset" by performing a CIP on the ceramic membranes and a backwash on the BAC column. Analysis at this point will occur according to the routine plan outlined in Section 3.2.

During the course of these experiments, particular attention would be paid to the effect of ozone dose on:

- Removal of organic compounds using measures such as TOC, BOD_5, True colour, UV-254 and UV-210 and micro-contaminants.
- Removal efficiency of indigenous microorganisms – if any can be detected.
- Fouling of CM and potential for reduction in backwash and CIP frequency.
- BAC activity by monitoring variation in the reduction of organic compounds similar to the system described across the ozone system. There would also be a need to monitor changes in nitrification processes, sulphate concentration and metals, particularly manganese, iron and silica. This activity will be correlated to the dissolved oxygen and ozone residual concentrations where possible.
- Fouling potential of RO membranes (this will be performed on sampled RO feed at the laboratory scale).

3.1.2.3 Aeration of BAC

During operation in Antarctica, the duration between batches is expected to increase significantly due to the large decrease in inflows. For most operations this is not a significant issue however the biological activity of the BAC column must be maintained at some level to ensure adequate operation on start-up. In particular it is important that the BAC not become anaerobic as this reduce the performance of the BAC. Three aeration strategies have been proposed:

- Low-level continuous aeration
- Intermittent aeration
- No aeration.

After the impact of ozone dose has been determined, three experiments will be performed to determine the impact of each strategy. The first of these will be used during ozone dose experiments and the analysis performed during this stage will represent the first condition. Subsequent to this, the two remaining strategies will be employed for one month each with analysis occurring as per the routine analysis. Particular attention will be paid to:

- BAC activity based on any variation in the reduction of organic compounds similar to the ozone dose experiments. Changes in nitrification, sulphate and metals would also be paid particular attention;
- Changes in backwashing frequency; and
- Fouling potential of RO membranes (performed on sampled RO feed at the laboratory scale).

3.1.2.4 pH Variation

The HAZOP and HACCP processes identified the potential impact of pH on the process as an unacceptable unknown in the system. It was proposed that this would need to be investigated at the pilot scale. Consequently, prior to the demonstration plant entering into a long term robustness test, it is proposed that pH spiking experiments occur. This will need to be developed in consultation with the Regulatory Advisory Committee as this would send the plant into operations outside those dictated in the HACCP and would necessarily bring about non-compliance events. The current plans aim to introduce four instantaneous pH spikes into the feed – two high and two low over the period of four weeks. These spikes will lie no more than 1 pH unit outside the acceptable range of the plant. The response of the plant will be monitored, with particular attention paid to how long the plant requires to recover from the pH spike. During this time twice weekly monitoring of the parameters outlined in Table 6 will be used on top of the existing monitoring plan. This will allow for the determination of variability in the BAC. The rest of the system will be monitored sufficiently through the on-line monitoring.

3.2 Routine Monitoring

A listing of all sample points, their locations and valve numbers according to the P&ID can be found in Appendix B. All sampling in this report will refer to the sample point numbers SP##.

Table 7 indicates online testing parameters that will be monitored routinely as part of the ongoing validation/verification of the recycled water process. These parameters are generally critical control points under the HACCP structure or are critical values the plant must operate under as part of its Recycled Water Management Strategy of the operating system. All testing is performed as per the manufacturer's instructions and must be recorded at least every 15 minutes to meet regulatory requirements. The test location is indicated as either in-line or side-stream depending on the location of the sensor. Four components of the online testing will be taken from TasWater monitoring points in the Self's Point treatment system and will be under their purview during operation. The sampling locations for the TasWater sensors are representative of the feedwater to the DAWTP.

Table 8 outlines testing that will occur on site but not online. All analysis will be performed with hand held devices that will be calibrated at least daily. Parameters highlighted in red in Table 8 have been identified as critical parameters in that there are limits applied in the regulations.

Table 9 outlines testing that will occur in the TasWater's Selfs Point laboratory. This is a NATA accredited laboratory. These analyses will be performed on a weekly basis. Parameters highlighted in red have been identified as critical parameters. TasWater will provide bacterial analysis for the plant.

Table 10 outlines testing that will occur at Victoria University's Werribee laboratories. This lab will be governed by the QA/QC plan outlined in Section 5. The analyses in these tables will be performed on a weekly basis. Parameters highlighted in red have been identified as critical parameters.

Further microbial analyses will be provided for verification purposes under contract by a NATA accredited laboratory. Due to the small scale of the plant somatic coliphage has been chosen as the indicator for viruses while *clostridia spp.* has been chosen as the indicator for protozoa. A total of ten samples will be taken for this analysis during plant operation. These will be checked for monthly with sampling occurring at the same eight sample points indicated for *E coli* in Table 9. Further microbial analysis will be performed for giardia/cryptosporidium and adenovirus and enterovirus on a quarterly basis on the product water only as a final check for the plant's performance. A total of four samples will be taken for this analysis during plant operation.

Monitoring of trace organic compounds will be provided by University of Melbourne. The focus of this study is to determine the fate of a range of organic compounds of concern during the advanced treatment process, the potential to better estimate the likelihood of removal and identify potential surrogates that could be used in place of direct monitoring. The analysis includes analysis of a range of compounds via GC-MS and LC-MS. Samples will be collected monthly from the feed, RO concentrate and product water. Samples will also be collected across each of the barriers monthly during experimental operation and quarterly during long-term robustness testing. More detail on the specific compounds can be found in the attached document *Micro-contaminant Assessment*.

Further to this analysis of the toxicity of the RO brine will be estimated. This will be performed through the use of *in vitro* yeast bioassays at the University of Melbourne. The RO will be samples monthly during operation for these experiments and the product stream every three months. More information on this may be found in the *Micro-contaminant Assessment*.

Table 7: Online monitoring strategy for the demonstration plant. Parameters have been grouped based around those identified as critical by the HACCP and those that are used other monitoring purposes.

Parameter	Stream Being Tested	Expected Range	Critical Value	Location	Reasoning
CRITICAL COMPONENTS					
Ammonia (TasWater)	Plant feed	0.1 to 30 $mg.L^{-1}$	> 5 $mg.L^{-1}$	?	Used to establish the ongoing robustness of upstream processing (CCP1)
Phosphate (TasWater)	Plant feed	0.1 to 10 $mg.L^{-1}$ as P	> 5 $mg.L^{-1}$	?	Used to establish the ongoing robustness of upstream processing (CCP1)
pH (on intake device)	Plant feed	6 to 8	< 6 or > 8	In-line	Used to establish the ongoing robustness of upstream processing (CCP1) and to set limits for operation of ozonation process (CCP2)
Turbidity (TasWater)	Plant feed	0 to 20 NTU	> 10 NTU	Side stream	Used to establish robustness of upstream processing and to establish worst case conditions under which ozone validation process is valid. (CCP1)
Temperature (L3033)	Plant feed	15 to 25 °C	< 12 or > 40 °C	In-line	Used to determine ozone contact time requirements (CCP4)
Residual Ozone (L3045)	After O_3 reactor tank	0.01 to 12 $mg.L^{-1}$	< 0.35 $mg.L^{-1}$	In-line	Used in the determination of ozone contact time (CCP4), to ensure a minimum ozone residual (CCP2) and estimate the ozone concentration on the membrane.
Turbidity (L3088)	After ceramic microfiltration system	0 to 10 NTU	> 0.5 NTU	Side stream	Indirect integrity measurement (CCP3)
UV Intensity (L3167)	At wall of UV Tank 1		TBD[1]	In line	Used to calculate UV dose (CCP4)
UV Intensity (L3171)	At wall of UV Tank 2		TBD[1]	In line	Used to calculate UV dose (CCP4)
Temperature (L3181)	After calcite filter	15 to 25 °C	[2]	In line	Used in the determination of chlorine contact time (CCP4)

Parameter	Stream Being Tested	Expected Range	Critical Value	Location	Reasoning
Chlorine (L3198)	Chlorine contact tank 1	0.4 to 1 $mg.L^{-1}$	< 0.38 $mg.L^{-1}$	Side stream	Used in the determination of chlorine contact time (CCP4) and for residual chlorine (CCP7)
Chlorine (L3205)	Chlorine contact tank 2	0.4 to 1 $mg.L^{-1}$	< 0.38 $mg.L^{-1}$	Side stream	Used in the determination of chlorine contact time (CCP4) and for residual chlorine (CCP7)
Conductivity (L3121)	RO feed	400 to 3000 $\mu S.cm^{-1}$	[2]	In line	Indirect integrity measurement (CCP5)
Conductivity (L3154)	RO permeate	0 to 500 $\mu S.cm^{-1}$	[2]	In line	Indirect integrity measurement (CCP5)
pH (L3188)	After calcite contactor	6 to 9	<6.5 and >9.0	Side stream	Used to determine to ensure effectiveness of chlorination (CCP6)
EXTRA MEASUREMENTS					
Ozone	Prior to mixer on dosing line	0 to 10 $mg.L^{-1}$		In line	Used to determine ozone dose
Chlorine (L3187)	After chlorination static mixer	0 to 5 $mg.L^{-1}$		Side stream	Used to determine chlorine dose
Ozone (L3083)	After ceramic microfiltration system	0 to 1 $mg.L^{-1}$	None	In line	Used to determine ozone residual after membrane filtration and in feed to BAC
Turbidity (L3105)	After BAC filter	0 to 10 NTU	3 NTU	Side stream	Used to determine the BAC backwash requirements. Last on-line turbidity measurement prior to UV
Conductivity (L3126)	Feed to 2nd RO vessel	400 to 12000 $\mu S.cm^{-1}$		In line	Secondary measurement of membrane integrity (not under HACCP)
Conductivity (L3131)	Feed to 3rd RO vessel	400 to 12000 $\mu S.cm^{-1}$		In line	Secondary measurement of membrane integrity (not under HACCP)
Conductivity (L3136)	Feed to 4th RO vessel	400 to 12000 $\mu S.cm^{-1}$		In line	Secondary measurement of membrane integrity (not under HACCP)
Conductivity (L3141)	Feed to 5th RO vessel	400 to 12000 $\mu S.cm^{-1}$		In line	Secondary measurement of membrane integrity (not under HACCP)
Conductivity (L3146)	RO concentrate	400 to 12000 $\mu S.cm^{-1}$		In line	Used in determination of rate of brine recycle

Parameter	Stream Being Tested	Expected Range	Critical Value	Location	Reasoning
Conductivity (L3124)	Permeate from 1st RO vessel	0 to 500 µS.cm^{-1}		In line	Secondary measurement of membrane integrity (not under HACCP)
Conductivity (L3124)	Permeate from 2nd RO vessel	0 to 500 µS.cm^{-1}		In line	Secondary measurement of membrane integrity (not under HACCP)
Conductivity (L3124)	Permeate from 3rd RO vessel	0 to 500 µS.cm^{-1}		In line	Secondary measurement of membrane integrity (not under HACCP)
Conductivity (L3124)	Permeate from 4th RO vessel	0 to 500 µS.cm^{-1}		In line	Secondary measurement of membrane integrity (not under HACCP)
Conductivity (L3124)	Permeate from 5th RO vessel	0 to 500 µS.cm^{-1}		In line	Secondary measurement of membrane integrity (not under HACCP)

1 These values will be determined after UV validation.

2 There are no critical values for these parameters, but they are used in combination with other parameters to determine critical values for specific unit operations.

Table 8: On site but offline analysis that will be performed on a weekly basis under the routine schedule, leading to a total of 37 samples during operation. Parameters highlighted in red indicate critical parameters where a maximum or minimum value has been specified in the regulations.

Parameter	Stream Being Tested	Expected Range	Reasoning
Turbidity (SP07)	After RO mix tank	0 to 1 NTU	Ensure that water reaching UV does not exceed critical turbidity of ***1 NTU***
Turbidity (SP04)	After ozone reactor tank	0 to 10 NTU	Check any change in turbidity after ozonation
Turbidity (Product)	Plant outlet	0 to 1 NTU	Ensure product quality. Maximum value of ***0.05 NTU*** set.
Colour (SP01)	Plant feed	TBD	Check potential impact on ozone demand
Colour (SP04)	After ozone tank	TBD	Determine reduction due to ozonation
Colour (SP05)	After ceramic membranes	TBD	Determine reduction due to catalytic membrane activity
Colour (SP06)	After BAC tank	TBD	Determine reduction due to BAC activity
Colour (SP12)	RO concentrate	TBD	Basic waste characterization
Colour (SP18)	Combined RO permeate	TBD	Determine colour in UV feed
Colour (SP21)	After final UV tank	TBD	Determine colour after UV treatment
Colour (Product)	Plant outlet	TBD	Check product quality. Maximum of ***5 HU*** set.
Conductivity (SP01)	Plant Feed	300 to 3000 $\mu S.cm^{-1}$	Determine conductivity in feed and highlight weekly variability
Conductivity (Product)	Plant Outlet	0 to 400 $\mu S.cm^{-1}$	Check product quality
pH (SP04)	After ozone reactor tank	6 to 8	Determine any pH variability due to ozonation
pH (SP06)	After BAC	6 to 8	Determine any pH variability due to BAC
pH (SP12)	RO concentration	6 to 8	Basic characterization of waste

Parameter	Stream Being Tested	Expected Range	Reasoning
pH (SP18)	Combined RO permeate	6 to 8	Characterization of RO permeate
pH (SP22)	After calcite contactor	6 to 9	Confirm effectiveness of calcite filter
pH (Product)	Plant outlet	6 to 9	Check product quality
Dissolved Oxygen (SP01)	Plant feed	TBD	Determine feed water characteristics
Dissolved Oxygen (SP03)	After ozone tank	TBD	Determine change due to ozonation
Dissolved Oxygen (SP05)	After ceramic membranes	TBD	Determine change due to catalytic membrane activity and likely concentration in feed to BAC to ensure aerobic conditions
Dissolved Oxygen (SP06)	After BAC	TBD	Confirm BAC outlet is still aerobic

Table 9: Analyses to be performed at TasWater. These analyses will occur on a weekly basis giving a total of 37 samples. Critical parameters are highlighted in red.

Parameter	Stream Being Tested	Expected Range	Reasoning
UV-210 (SP01)	Plant feed	TBD	To ascertain changes in different types of organics during advanced treatment
UV-210 (SP04)	After ozone contact tank	TBD	To ascertain changes in different types of organics during advanced treatment
UV-210 (SP05)	After ceramic membranes	TBD	To ascertain changes in different types of organics during advanced treatment
UV-210 (SP06)	After BAC	TBD	To ascertain changes in different types of organics during advanced treatment
UV-210 (SP07)	After RO mix tank	TBD	To ascertain changes in different types of organics during advanced treatment
UV-210 (SP12)	RO concentrate	TBD	To ascertain changes in different types of organics during advanced treatment
UV-210 (SP18)	Combined RO permeate	TBD	To ascertain changes in different types of organics during advanced treatment
UV-210 (SP21)	After UV tanks	TBD	To ascertain changes in different types of organics during advanced treatment
UV-210 (SP22)	After calcite filter	TBD	To ascertain changes in different types of organics during advanced treatment
UV-210 (Product)	Plant outlet	TBD	To ascertain changes in different types of organics during advanced treatment
UV-254 (SP01)	Plant feed	TBD	To ascertain changes in different types of organics during advanced treatment
UV-254 (SP04)	After ozone contact tank	TBD	To ascertain changes in different types of organics during advanced treatment
UV-254 (SP05)	After ceramic membranes	TBD	To ascertain changes in different types of organics during advanced treatment
UV-254 (SP06)	After BAC	TBD	To ascertain changes in different types of organics during advanced treatment
UV-254 (SP07)	After RO mix tank	TBD	To ascertain changes in different types of organics during advanced treatment
UV-254 (SP12)	RO concentrate	TBD	To ascertain changes in different types of organics during advanced treatment

Parameter	Stream Being Tested	Expected Range	Reasoning
UV-254 (SP18)	Combined RO permeate	TBD	To ascertain changes in different types of organics during advanced treatment
UV-254 (SP21)	After UV tanks	TBD	To ascertain changes in different types of organics during advanced treatment
UV-254 (SP22)	After calcite filter	TBD	To ascertain changes in different types of organics during advanced treatment
UV-254 (Product)	Plant outlet	TBD	To ascertain changes in different types of organics during advanced treatment
Total Suspended Solids (SP01)	Plant feed	3 to 50 $mg.L^{-1}$	Feed water characterization Limit of ***10 $mg.L^{-1}$*** set by functional design for operation of ozone.
BOD_5 (SP01)	Plant feed	1 to 30 $mg.L^{-1}$	Feed water characterization Limit of ***20 $mg.L^{-1}$*** set in functional design
BOD_5 (SP04)	After ozone tank	TBD	Determine the impact of ozone on biodegradable organics
BOD_5 (SP05)	After ceramic membranes	TBD	Determine impact of catalytic membrane ozonation on biodegradable organics
BOD_5 (SP06)	After BAC tank	TBD	Determine efficacy of BAC
BOD_5 (SP12)	After RO mix tank	TBD	Identify any build-up of biodegradable components in the RO system.
BOD_5 (Product)	Plant outlet	TBD	Product quality check
Total Nitrogen (SP01)	Plant feed	0.1 to 40 $mg.L^{-1}$	Feed water characterization Limit of ***10 $mg.L^{-1}$*** set in functional design
Total Nitrogen (SP06)	After BAC tank	TBD	
Total Nitrogen (SP12)	RO concentrate	TBD	Waste characterization
Total Nitrogen (SP18)	Combined RO permeate	TBD	
Total Nitrogen (Product)	Plant outlet	TBD	Product quality check

Parameter	Stream Being Tested	Expected Range	Reasoning
Nitrate/Nitrite (SP01)	Plant feed	0 to 10 $mg.L^{-1}$	Feed water characterization *For later review (online monitoring may be sufficient)*
Nitrate/Nitrite (SP04)	After ozone tank	TBD	
Nitrate/Nitrite (SP12)	RO concentrate	TBD	Waste characterization
Nitrate/Nitrite (SP18)	RO permeate	TBD	Confirmation of removal
Ammonia (SP01)	Plant feed	0 to 30 $mg.L^{-1}$	Feed water characterization
Ammonia (SP04)	After ozone tank	TBD	Confirmation of ammonia removal
Ammonia (product)	Plant outlet	0 to 10 $mg.L^{-1}$	Product quality check. Limit of ***0.1 $mg.L^{-1}$*** set.
Total Dissolved Solids (SP01)	Plant feed	0 to 1000 $mg.L^{-1}$	Feed water characterization
Total Dissolved Solids (SP12)	RO concentrate	0 to 4000 $mg.L^{-1}$	Waste characterization
Total Dissolved Solids (Product)	Plant outlet	0 to 200 $mg.L^{-1}$	Product quality check. Limit of ***500 $mg.L^{-1}$*** set.
E coli (SP01)	Plant feed	TBD	Feed water characterization
E coli (SP04)	After ozone contact tank	TBD	Verification of reduction
E coli (SP05)	After ceramic membranes	TBD	Verification of reduction
E coli (SP06)	After BAC tank	TBD	Verification of reduction
E coli (SP12)	RO concentrate	TBD	Waste characterization

Parameter	Stream Being Tested	Expected Range	Reasoning
E coli (SP18)	Combined RO permeate	TBD	Verification of reduction
E coli (SP21)	After UV tanks	TBD	Verification of reduction
E coli (Product)	Plant outlet	TBD	Product quality check
Total coliforms (SP01)	Plant feed	TBD	Feed water characterization
Total coliforms (SP04)	After ozone contact tank	TBD	Verification of reduction
Total coliforms (SP05)	After ceramic membranes	TBD	Verification of reduction
Total coliforms (SP06)	After BAC tank	TBD	Verification of reduction
Total coliforms (SP12)	RO concentrate	TBD	Waste characterization
Total coliforms (SP18)	Combined RO permeate	TBD	Verification of reduction
Total coliforms (SP21)	After UV tanks	TBD	Verification of reduction
Total coliforms (Product)	Plant outlet	TBD	Product quality check
Alkalinity (SP01)	Plant feed	TBD	Feed water characterization
Alkalinity (SP18)	Combined RO permeate	0 to 10 $mg.L^{-1}$	Confirmation of lack of alkalinity *To be reviewed during operation*
Alkalinity (SP22)	After calcite filter	0 to 80 $mg.L^{-1}$	Confirm and quantify calcite dissolution
Alkalinity (product)	Plant outlet	0 to 80 $mg.L^{-1}$	Product quality check. Minimum requirement of ***40 $mg.L^{-1}$ as $CaCO_3$***

Table 10: Analyses to be performed by Victoria University laboratories. These analyses will occur on a weekly basis with a total of 37 samples. Critical parameters are highlighted in red.

Parameter	Stream Being Tested	Expected Range	Reasoning
Total phosphorus (SP01)	Plant feed	0.1 to 10 $mg.L^{-1}$	Feed characterization
Total phosphorus (SP04)	After ozone contact tank	0.1 to 10 $mg.L^{-1}$	
Total phosphorus (SP05)	After ceramic membranes	0.1 to 10 $mg.L^{-1}$	
Total phosphorus (SP06)	After BAC tank	0.1 to 10 $mg.L^{-1}$	
Total phosphorus (SP12)	RO concentrate	0.4 to 40 $mg.L^{-1}$	Waste characterization. Monitor for scale potential
Total phosphorus (SP18)	Combined RO permeate	0 to 1 $mg.L^{-1}$	
Total phosphorus (Product)	Plant outlet	0 to 1 $mg.L^{-1}$	Product quality check
Total organic carbon (SP01)	Plant feed	0 to 50 $mg.L^{-1}$	Feed characterization
Total organic carbon (SP04)	After ozone contact tank	TBD	Identification of potential surrogate for TrOCs
Total organic carbon (SP05)	After ceramic membranes	TBD	Identification of potential surrogate for TrOCs
Total organic carbon (SP06)	After BAC tank	TBD	Identification of potential surrogate for TrOCs
Total organic carbon (SP07)	After RO mix tank	TBD	Identification of potential surrogate for TrOCs
Total organic carbon (SP12)	RO concentrate	TBD	Identification of potential surrogate for TrOCs

Parameter	Stream Being Tested	Expected Range	Reasoning
Total organic carbon (SP18)	Combined RO permeate	TBD	Identification of potential surrogate for TrOCs
Total organic carbon (SP21)	After UV tank	TBD	Identification of potential surrogate for TrOCs
Total organic carbon (SP22)	After calcite filter	TBD	Identification of potential surrogate for TrOCs
Total organic carbon (Product)	Plant outlet	TBD	Product quality check
Metals[1] (SP01)	Plant feed	TBD	Feed characterization
Metals[1] (SP04)	After ozone contact tank	TBD	
Metals[1] (SP05)	After ceramic membranes	TBD	
Metals[1] (SP06)	After BAC tank	TBD	
Metals[1] (SP07)	After RO mix tank	TBD	
Metals[1] (SP12)	RO concentrate	TBD	
Metals[1] (SP18)	Combined RO permeate	TBD	
Metals[1] (SP21)	After UV tank	TBD	
Metals[1] (SP22)	After calcite filter	TBD	
Metals[1] (Product)	Plant outlet	TBD	Product quality check, limits apply as per the Functional Design and relevant guidelines
Anions[2] (SP01)	Plant feed	TBD	Feedwater characterization. Monitoring of bromide is a high priority.

Parameter	Stream Being Tested	Expected Range	Reasoning
Anions[2] (SP04)	After ozone contact tank	TBD	Quantification of bromate formation
Anions[2] (SP05)	After ceramic membranes	TBD	Quantification of catalytic effects on bromate formation
Anions[2] (SP06)	After BAC tank	TBD	Quantification and confirmation of bromate removal by BAC
Anions[2] (SP12)	RO concentrate	TBD	Waste characterization
Anions[2] (SP18)	Combined RO permeate	TBD	
Anions[2] (Product)	Plant outlet	TBD	Product quality check. Limits in place as per guidelines
Fluoride (SP01)	Plant feed	TBD	Feed characterization
Fluoride (Product)	Plant outlet	TBD	Produce quality check. Limit in pace at ***1.5 mg.L^{-1}***

1. Metals analysis will include Al, Ca, Fe, Mg, Mn, Ni, Si and any other metals identified via the feedwater baseline characterization.
2. Anion analysis includes Cl^-, Br^- and BrO_3^-. It may be extended to include I^-, CN^-, S^{2-} depending on the outcome of feedwater baseline characterization and the approval of the technique.

3.3 Pilot Test Schedule

The test schedule for the pilot plant will need to be flexible due to the need for the BAC column to be operating in biological mode. As such, no firm dates can be set at this point; however the Gantt chart In Figure 1 provides the anticipated schedule assuming three months is required for BAC acclimatization.

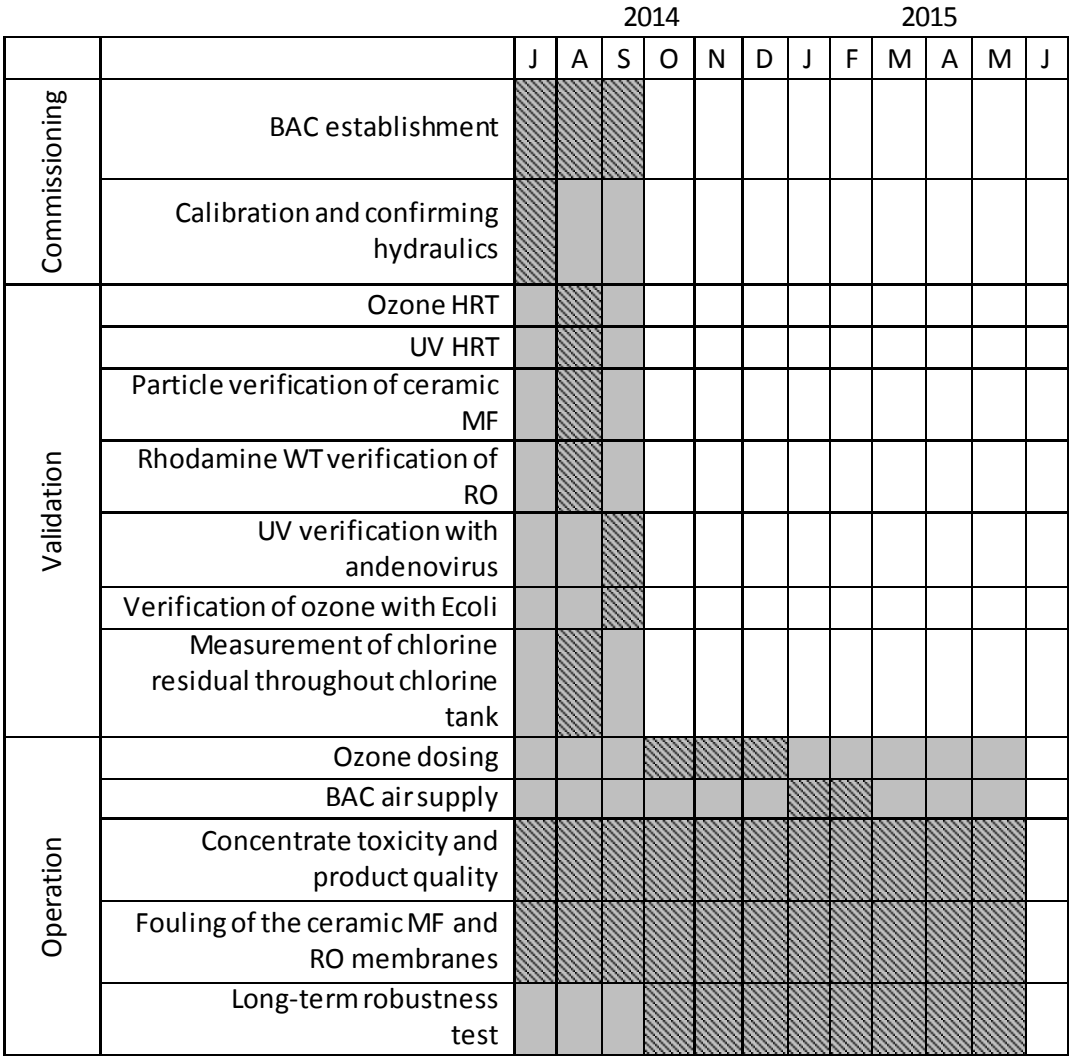

Figure 1: Gantt Chart describing the current experimental plan for the demonstration plant.

4. Analytical Procedures

4.1 On Site Analysis

On site analysis as detailed in Table 8 occurs on a weekly basis and will be performed using hand held devices according to the relevant SWI. These are:

- Measurement of Turbidity
- Measurement of Conductivity
- Measurement of pH
- Measurement of Dissolved Oxygen Content
- Measurement of APHA Colour

The results of analysis should be recorded in the data sheet found in Appendix C. The results should be scanned and emailed to Adrian Knight with a carbon copy sent to Prof Stephen Gray and Prof Peter Scales by 4pm on the day they are collected. Hardcopies should be stored in the analytical folder.

4.2 Laboratory Sampling Requirements

Off-site analysis will be performed at the University of Melbourne, TasWater's Self's Point Plant or Victoria University. Samples will be collected as per the Sampling schedule in Table 11. Samples must be collected following the procedures described in the SWI.

4.2.1 Sampling

Samples should be collected using two types of sample bottles or containers. Samples for inorganic analysis should be collected in polyethylene, polypropylene or polytetrafluoroethlyene (Teflon) bottles and containers. Sampled for organic analysis should be collected in amber glass bottles. The containers must not have been previously used. Before the sample is collected the container should be thoroughly rinsed in the sample. All containers should be completely filled (that is to say there should be no headspace in the container). Containers should be immediately labelled with:

- The time and date of sampling
- The location from which the sample was taken
- The name of the person collecting the sample

After collection samples should be refrigerated at 4 °C.

Sampling will occur as per the sampling schedule. The sample size and container types for each sample point are given in Table 11. Samples will need to be delivered to different sites in a timely manner. Samples for TasWater can be hand delivered. All other samples should be send to Adrian Knight at the University of Melbourne to arrange subsampling and distribution to the relevant laboratories.

In line with the QA/QC plan, double samples should be taken of the feed (SP01), RO Concentrate (SP12) and outlet streams every month, with a triplicate sample taken at each point quarterly.

Table 11: Sampling Schedule.

Sample Point	Container	Volume	Analysis	On-site Treatment	Regularity	Sample Destination
SP01	Amber Glass	2 L	BOD_5, UV-254, UV-210, TSS, TN, Nitrate, Ammonia		Weekly Double sample Monthly	TasWater
SP01	Amber Glass	100 mL	TOC		Weekly Double sample Monthly Triple Sample Quarterly	Victoria University
SP01	Bio-bottle	500 mL	E coli, total coliforms	As per analyst instructions	Weekly Double sample Monthly	TasWater
SP01	PE/PP	1 L	TDS, Alkalinity		Weekly Double sample Monthly	TasWater
SP01	PE/PP	1 L	Anions, Metals, TP, Fluoride		Weekly Double sample Monthly Triple Sample Quarterly	Victoria University
SP01	Bio-bottle	1 L	Somatic coliphage, clostridria	As per analyst instructions	Monthly	TBD
SP01	Pre-prepared Glass	4 x 1 L	Trace Organic Compounds		Monthly	University of Melbourne
SP01	Pre-prepared Glass	1 L	Bioassay		Quarterly	University of Melbourne
SP04	Amber Glass	2 L	BOD_5, UV-254, UV-210, TN, Nitrate, Ammonia		Weekly	TasWater

Sample Point	Container	Volume	Analysis	On-site Treatment	Regularity	Sample Destination
SP04	Amber Glass	100 mL	TOC		Weekly	Victoria University
SP04	Bio-bottle	500 mL	E coli, total coliforms	As per analyst instructions	Weekly	TasWater
SP04	PE/PP	1 L	Anions, Metals, TP		Weekly	Victoria University
SP04	Bio-bottle	1 L	Somatic coliphage, clostridria	As per analyst instructions	Monthly	TBD
SP04	Pre-prepared Glass	4 x 1 L	Trace Organic Compounds		Monthly during ozone dosing experiments Quarterly during robustness tests	University of Melbourne
SP05	Amber Glass	100 mL	UV-254, UV-210		Weekly	TasWater
SP05	Amber Glass	100 mL	TOC		Weekly	Victoria University
SP05	Bio-bottle	500 mL	E coli, total coliforms	As per analyst instructions	Weekly	TasWater
SP05	PE/PP	1 L	Anions, Metals, TP		Weekly	Victoria University
SP05	Bio-bottle	1 L	Somatic coliphage, clostridria	As per analyst instructions	Monthly	TBD

Sample Point	Container	Volume	Analysis	On-site Treatment	Regularity	Sample Destination
SP05	Pre-prepared Glass	4 x 1 L	Trace Organic Compounds		Monthly during ozone dosing experiments Quarterly during robustness tests	University of Melbourne
SP06	Amber Glass	2 L	BOD_5, UV-254, UV-210, TN		Weekly	TasWater
SP06	Amber Glass	100 mL	TOC		Weekly	Victoria University
SP06	Bio-bottle	500 mL	E coli, total coliforms	As per analyst instructions	Weekly	TasWater
SP06	PE/PP	1 L	Anions, Metals, TP		Weekly	Victoria University
SP06	Bio-bottle	1 L	Somatic coliphage, clostridria	As per analyst instructions	Monthly	TBD
SP06	Pre-prepared Glass	4 x 1 L	Trace Organic Compounds		Monthly during ozone dosing experiments Quarterly during robustness tests	University of Melbourne
SP07	Amber Glass	100 mL	UV-254, UV-210		Weekly	TasWater
SP07	Amber Glass	100 mL	TOC		Weekly	Victoria University
SP07	PE/PP	500 mL	Metals		Weekly	Victoria University
SP12	Amber Glass	2 L	BOD_5, UV-254, UV-210, TN, Nitrate		Weekly Double sample monthly	TasWater

Sample Point	Container	Volume	Analysis	On-site Treatment	Regularity	Sample Destination
SP12	Amber Glass	100 mL	TOC		Weekly Double sample monthly Triple sample quarterly	Victoria University
SP12	Bio-bottle	500 mL	E coli, total coliforms	As per analyst instructions	Weekly Double sample monthly	TasWater
SP12	PE/PP	1 L	TDS		Weekly	TasWater
SP12	PE/PP	1 L	Anions, Metals, TP		Weekly Double sample monthly Triple sample quarterly	Victoria University
SP12	Bio-bottle	1 L	Somatic coliphage, clostridria	As per analyst instructions	Monthly	TBD
SP12	Pre-prepared Glass	4 x 1 L	Trace Organic Compounds		Monthly	University of Melbourne
SP12	Pre-prepared Glass	1 L	Bioassay		Monthly	University of Melbourne
SP18	Amber Glass	2 L	BOD_5, UV-254, UV-210, TN, Nitrate, Ammonia, Alkalinity		Weekly	TasWater
SP18	Amber Glass	100 mL	TOC		Weekly	Victoria University
SP18	Bio-bottle	500 mL	E coli, total coliforms	As per analyst instructions	Weekly	TasWater

Sample Point	Container	Volume	Analysis	On-site Treatment	Regularity	Sample Destination
SP18	PE/PP	1 L	Anions, Metals, TP		Weekly	Victoria University
SP18	Bio-bottle	1 L	Somatic coliphage, clostridria	As per analyst instructions	Monthly	TBD
SP18	Pre-prepared Glass	4 x 1 L	Trace Organic Compounds		Monthly during ozone dosing experiments Quarterly during robustness tests	University of Melbourne
SP21	Amber Glass	100 mL	UV-254, UV-210		Weekly	TasWater
SP21	Amber Glass	100 mL	TOC		Weekly	Victoria University
SP21	Bio-bottle	500 mL	E coli, total coliforms	As per analyst instructions	Weekly	TasWater
SP21	PE/PP	250 mL	Metals		Weekly	Victoria University
SP21	Bio-bottle	1 L	Somatic coliphage, clostridria	As per analyst instructions	Monthly	TBD
SP21	Pre-prepared Glass	4 x 1 L	Trace Organic Compounds		Monthly during ozone dosing experiments Quarterly during robustness tests	University of Melbourne
SP22	Amber Glass	100 mL	UV-254, UV-210		Weekly	TasWater
SP22	Amber Glass	100 mL	TOC		Weekly	Victoria University

Sample Point	Container	Volume	Analysis	On-site Treatment	Regularity	Sample Destination
SP22	PE/PP	250 mL	Metals		Weekly	Victoria University
Plant Outlet	Amber Glass	2 L	BOD_5, UV-254, UV-210, TN, Ammonia, Alkalinity		Weekly Double sample monthly	TasWater
Plant Outlet	Amber Glass	100 mL	TOC		Weekly Double sample monthly Triple sample quarterly	Victoria University
Plant Outlet	Bio-bottle	500 mL	E coli, total coliforms	As per analyst instructions	Weekly Double sample monthly	TasWater
Plant Outlet	PE/PP	1 L	Anions, Metals, TP, Fluoride		Weekly Double sample monthly Triple sample quarterly	Victoria University
Plant Outlet	Bio-bottle	1 L	Somatic coliphage, clostridria	As per analyst instructions	Monthly	TBD
Plant Outlet	Bio-bottle	2 L	Giardia/cryptosporidium, adenovirus, enterovirus	As per analyst instructions	Quarterly	TBD
Plant Outlet	Pre-prepared Glass	4 x 1 L	Trace Organic Compounds		Monthly	University of Melbourne
Plant Outlet	Pre-prepared Glass	1 L	Bioassay		Quarterly	University of Melbourne

4.3 Analytical Processes

Table 12 outlines the laboratory techniques that will be used in monitoring according to the routine monitoring plan. In general they are taken from Standard Methods for the Examination of Water and Wastewater or methods derived therefrom.

Table 12: Methods to be used for parameter determination throughout he project.

Parameter	Test Method
pH	Method 4500-H^+ B from *Standard Methods*.
Turbidity	Method 2130 B from *Standard Methods*.
Temperature	Method 2550 B from *Standard Methods*.
Ozone	Indigo method – Method 4500-O_3 B from *Standard Methods*.
Chlorine	DPD Chlorine – Hach Method 8021 based on Method 4500-Cl G from *Standard Methods*.
Bromine	DPD Bromine – Hach Method 8016.
Conductivity	Hand held meter – Method 2510 B from *Standard Methods*.
UV Intensity	TBD based on manufacturer's recommendations
Dissolved Oxygen	Hand held meter – Method 4500-O G from *Standard Methods*
UV-254	
UV-210	
BOD_5	Method 5210 B from *Standard Methods*
Total Nitrogen	To be confirmed.
Nitrate/Nitrite	To be confirmed
Ammonia	To be confirmed
Total Dissolved Solids	Method 2540 C from *Standard Methods*
Total Suspended Solids	Method 2540 D from *Standard Methods*
Alkalinity	Method 2320 B from *Standard Methods.*
Total Phosphorus	Modified Method 3120 B from *Standard Methods*.
Total Organic Carbon	Method 5310 B from *Standard Methods*
Metals	Method 3120 B from *Standard Methods*
Fluoride	Method 4500-F^- C from *Standard Methods*
Anions	Method 4110 B from *Standard Methods*

4.4 Data Handling Protocol

All online data should be collected by the on-site computer in an Access database (or nearest equivalent) with a record of the instrument number and the time the analysis was recorded. The data should be available to all researchers on the project via the internet upon request.

The results of analysis performed should be recorded in the data sheet found in Appendix C. The results should be scanned and emailed to Adrian Knight with a carbon copy sent to Prof Stephen Gray and Prof Peter Scales by 4pm on the day they are collected. Hardcopies should be stored in the analytical folder. All data will be entered into Access or other database and stored using the University of Melbourne Cloud service.

All data generated by analysis at TasWater, University of Melbourne and Victoria University will be uploaded onto the University of Melbourne cloud service once the data has been generated. In the case of TasWater if access is not possible the data should be emailed to Adrian Knight with carbon copies sent to Prof Stephen Gray and Prof Peter Scales. Hardcopies of results should be mailed to Adrian Knight for appropriate archiving.

4.5 Data Reporting

Data collected will be plotted over time and analysed using the metrics described in Section 1.2. All monitoring of critical parameters will be plotted and average data tabulated to be reported on a monthly basis. The number of breech in the guideline values will be reported every month. Every month a short report will be prepared detailing this and other analysis performed.

5. Quality Assurance / Quality Control

5.1 QA/QC of On-line Monitoring Parameters

Over the course of the demonstration all on-line measurement will be verified on a weekly basis by operators. This is to ensure that measurements are accurate to within 5%. The list of instruments that must be tested and the test method to be used for verification is shown in Table 13. Conductivity, pH, turbidity and temperature will all be verified using handheld devices made available by Victoria University. These meters must first be calibrated according to the relevant SWIs. Ozone and chlorine residuals are measured using colorimetric techniques on a hand held colorimeter or the UV/Vis spectrophotometer in the TasWater labs. Where the reading on a hand-held device varies by more than 5% of the on-line recording, a calibration of the online meter will be immediately performed. The calibration of any on-line device must occur according to the relevant SWI. There is currently no procedure for devices under the purview of TasWater. There is, however, monitoring occurring in the feed that can be used as a weekly verification for the data they provide.

Table 13: Test methods to be used for verification of online monitoring devices.

Parameter	Device Numbers	Test Method
pH	*On intake device*, *L3188*	Hand held meter – Method 4500-H^+ B from *Standard Methods*.
Turbidity	*L3088*, L3105	Hand held meter – Method 2130 B from *Standard Methods*.
Temperature	*L3033*, *L3181*,	Hand held meter – Method 2550 B from *Standard Methods*.
Ozone	*L3045*, L3083	Indigo method – Method 4500-O_3 B from *Standard Methods*.
Chlorine	*L3198*, *L3205*, L3187	DPD Chlorine – Hach Method 8021 based on Method 4500-Cl G from *Standard Methods*.
Conductivity	*L3121*, *L3154*, L3126, L3131, L3136, L3141, L3146, L3124, L3129, L3129, L3134, L3139, L3144	Hand held meter – Method 2510 B from *Standard Methods*.
UV Intensity	*L3167, L3171*	TBD based on manufacturer's recommendations

5.2 Off-line, Onsite Testing QA / QC

All hand held devices used for onsite testing will be calibrated on a daily basis. The calibration standards used will be traceable standards from pre-approved suppliers. Operators must always check that the standards are in date before use. All onsite calibration will be performed according to the relevant SWI.

5.3 Offsite Testing QA / QC

5.3.1 Sample Collection and Storage

All samples collected for offsite testing will be labelled with:

- the time and date of sampling
- the location from which the sample was taken (sample point number)
- the initials of the person taking the sample.

The samples should be logged in a packing list as they are collected and signed by the person collecting the samples. This packing list must be included with the samples when they are sent to University of Melbourne. Once collected the samples should be stored at 4°C until transit is arranged.

Double volumes of specific samples will be provided to the university laboratorys on a monthly basis for QC purposes. Two sets of sample containers will be filled and all containers are labelled with a single sample number. The laboratory should be alerted as to which sample is to be used for QC analysis by notation on the sample container label and the packing list.

QC samples must, at a minimum, be provided once every four weeks from the following sample points:

- SP01 (Plant feed)
- SP12 (RO concentrate)
- Plant outlet

Prof Stephen Gray or Prof Peter Scales may request extra QC analyses at their discretion.

Triplicate volumes of specific samples will be provided to the university laboratory on a quarterly basis for external auditing purposes. Three sets of sample containers will be filled and all containers labelled with a single sample number. The laboratory should be alerted as to which sample is to be used for auditing analysis by notation on the sample container label and the packing list. Once received, the university will forward on one of the three samples to a NATA accredited lab for verification.

5.3.2 Sample Receipt and Logging

Upon receipt at University of Melbourne or TasWater all samples will be checked and assigned a sample number. Samples being sent on to other testing facilities will be verified on the appropriate packing list being forwarded. When sub-sampling of containers occurs, all new containers will be immediately labelled with the same sample number and description. All samples and subsamples will be stored at 4°C until analysis is performed. All samples should be entered into an Excel log specific to that week of sampling stored on a networked drive at the site of testing. Results will be logged in this spreadsheet along with the name of the person performing the analysis. Once all analysis is complete at the testing facility for that week, the results will be uploaded to the University of Melbourne cloud service.

5.3.3 Sample Preparation

Sample preparation will follow the procedures outlined in the relevant Standard Method, Hach Method or as per the manufacturer's instructions as required.

5.3.4 Calibration and Standard Preparation

Wherever possible, traceable standards (from a pre-approved supplier) will be used in all analyses. The exception for this is TOC where primary standards will be used. Standards used in calibration and required for QC will be produced from these standards. The prepared standards will be labelled with the date of preparation and will be retained for no longer than 1 month.

Calibration standards will be prepared as outlined by the relevant Method.

Calibration will be performed as per manufacturer's instructions on a monthly basis of all analyses except ICP which will use a daily calibration procedure.

Any balance used in TDS measurements must be checked for accuracy on a weekly basis. They should have been professionally calibrated within the last 12 months.

5.3.5 SQC Sample from Selfs Point

L of the SQC sample collected in a PE container and 1 L collected in a glass container at Selfs Point (from the demonstration plant feed) will be provided to Victoria University. Victoria University will immediately perform ICP, TOC and ion chromatography analysis on this sample 10 times, starting from the sample preparation. This data will be used to generate a range graph. The mean range (difference between the highest and lowest samples) of the 10 replicates will be used to determine a warning limit (2.512 times the mean range) and a control limit (3.267 times the mean range) for analysis. The SQC sample will then be run at least once per day when analysis is performed and added to the range graph.

Any result in above the warning limit will require investigation to determine likely cause and impact on results. The SQC sample should, in the first instance, be re-run. If the result again lies above the warning limit, the calibration should be re-performed. If this does not resolve the problem, analysis should be suspended until professional investigation can be performed. When the problem is resolved, the samples contained within the suspect ICP run will be re-analysed.

Any result above the control range will require analysis to be suspended. The calibration should be re-performed and sample re-run. If the problem is not resolved, a professional investigation should be performed. Upon resolution of the problem, the samples that were analysed in the suspect run will be re-analysed.

During plant operation the SQC sample will need to be replaced on regular basis. 1 L sample in a glass container and 1 L in a PE container will be provided monthly. A further 5 L in a plastic container will be provided every six months.

APPENDIX A

Site Map and Important Locations

Google Map image of Self's Point Treatment Plant marking location of demonstration plant (yellow), the plant's feedwater source (red), the plant's discharge point (blue) and the TasWater laboratory (green)

APPENDIX B

List of Sample Point and Corresponding Valve Numbers

Description	Sample Point Number	Valve Number of Sample Point
Feed Water	SP01	None assigned
Ozone Sidestream After Mixing	SP02	L3040
After Ozone Tank	SP04	L3044
Ceramic Membrane Permeate	SP05	L3084
After BAC Tank	SP06	L3096
After RO Mix Tank	SP07	L3122
RO Feed Vessel 2	SP08	L3127
RO Feed Vessel 3	SP09	L3132
RO Feed Vessel 4	SP10	L3137
RO Feed Vessel 5	SP11	L3142
RO Concentrate	SP12	L3147
RO Permeate Vessel 1	SP13	L3125
RO Permeate Vessel 2	SP14	L3130
RO Permeate Vessel 3	SP15	L3135
RO Permeate Vessel 4	SP16	L3140
RO Permeate Vessel 5	SP17	L3155/L3145
Combined RO Permeate	SP18	L3155
After UV Tank 1	SP19	L3169
After UV Tank 2	SP20	L3173
After UV Tank 3	SP21	L3177
After Calcite Filter	SP22	L3182
After Chlorine Static Mixer	SP23	L3189
After Chlorine Contact Tank 1	SP24	L3199
After Chlorine Contact Tank 2	SP25	L3206
Plant Outlet		
After CIP Tank	SP26	L3219

APPENDIX C

Sheet for Recording On-Site Analysis

TO BE ISSUED