Australian Water Recycling
Centre of Excellence

Demonstration of robust water recycling: Functional Design

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Demonstration of robust water recycling: Functional design

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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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PURPOSE

This Functional Description details the design and operation of the Davis Advanced Water Treatment Plant (AWTP) that will ultimately be located at Davis Station in Antarctica. It includes a full description of the equipment as well as modes of operation, control philosophies and performance criterion.

SCOPE

The scope of the advanced water treatment process includes all unit processes within the advanced water treatment plant, including ozonation, ceramic microfiltration (MF), biological activated carbon (BAC) filtration, reverse osmosis (RO), UV disinfection, calcite contactor and chlorine disinfection. It also includes unit processes from the secondary treatment plant, specifically the coagulation system for phosphorous removal and the membrane bioreactor, as well as effluent monitoring from the secondary wastewater treatment system. In addition to these unit processes the Davis AWTP incorporates a number of ancillary systems such as service and process air, backwash water and chemical clean-in-place (CIP). The Davis AWTP will also incorporate electrical and control (SCADA) systems.

DEFINITIONS

- LRV – Log Reduction Value.
- CT – CT Stands CT stands for **concentration (C)** and **contact time (T)**. It is the result of multiplying the disinfectant residual concentration by the contact time. CT is a measure of disinfection effectiveness for the time that the water and disinfectant are in contact. “C” is the disinfectant residual concentration measured in mg/L at peak hourly flow and “T” is the time that the disinfectant is in contact with the water at peak hourly flow. The contact time (T) is measured from the point of disinfectant injection to a point where the residual is measured before the first customer (or the next disinfectant application point) and is measured in minutes.
- TrOC – Trace organic compounds
- CoC - Contaminants of concern including TrOCs and metals

REFERENCES

	Title	*Reference*
1	*Davis Station Advanced Water Treatment Plant P&IDs*	*Attachments*
2	*Davis Station Advanced Water Treatment Plant Process Flow – Barrier No.2 – Ozone Disinfection*	*Attachments*
3	*Davis Station Advanced Water Treatment Plant Process Flow – Barrier No.3 – MF Ceramic*	*Attachments*
4	*Davis Station Advanced Water Treatment Plant Process Flow – Barrier No.4 – BAC Filter*	*Attachments*
5	*Davis Station Advanced Water Treatment Plant Process Flow – Barrier No.5 – Reverse Osmosis*	*Attachments*
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1. OPERATIONAL DESCRIPTION

1.1 Overview

The Davis AWTP will be located at Davis station in Antarctica. The Davis AWTP will be located adjacent to the wastewater treatment plant and recycling areas at Davis Station.

The Davis AWTP will produce up to 22 kL per day of treated water suitable for direct potable reuse (DPR). This will be achieved via a multi-barrier treatment process incorporating ozone, ceramic microfiltration (MF), biological activated carbon (BAC) filtration, RO, UV disinfection, calcite contactor and chlorine disinfection.

1.2 Design Parameters

1.2.1 Water Quality Parameters

The feed water quality to the advanced treatment plant will meet the following specifications:

Table 1: Design feedwater quality for the advanced treatment process.

Parameter	Minimum value	Maximum Value	Units	Comment
Turbidity		1	NTU	Ensure ozone performance
Boichemical Oxygen Demand (BOD5)		20	mg/L	
pH	6	8		Ensure ozone and BAC performance
Suspended solids		10	mg/L	Ensure ozone performance
Total nitrogen		10	mg/L	

The product water quality from the advanced treatment plant will meet the requirement of the Australia Drinking Water Guideline. Some specifications listed in Table 2.

Table 2: Design product water quality for the advanced treatment process.

Parameter	Minimum value	Maximum Value	Units	Comment
Turbidity		0.05	NTU	
pH	6	8		
Chlorine residual	0.05		mg/L	Ensure adequate disinfection after detention time
alkalinity	40		mg/L CaCO3	Prevent corrosion in water system
TDS		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	ADWG
colour		5	HU	
Taste & odour		Acceptable		Based on subjective taste test
Total coliforms		0	org/100mL	ADWG
Ecoli		0	org/100mL	ADWG
THMs		0.2	mg/L	
NDMA		100	ng/L	ADWG 6, version 2.0, Updated Dec 2013

Additional Trace Organic Compound (TrOC) limits are required to be met as detailed in ADWG. The required LRVs for pathogens will be as specified based on the untreated wastewater.

Table 3: Minimum LRVs for production of drinking water at Davis station[1] 2013 #621.

Pathogen	LRV	Comment
Viruses	14.5	Required LRV 12.1 for norovirus from study by Barker et al 2013[1]
Bacteria	14.5	Required LRV 12.3 for campylobacter study by Barker et al 2013[1]
Protozoa	12	Required LRV 10.4 for giardia from study by Barker et al 2013[1]

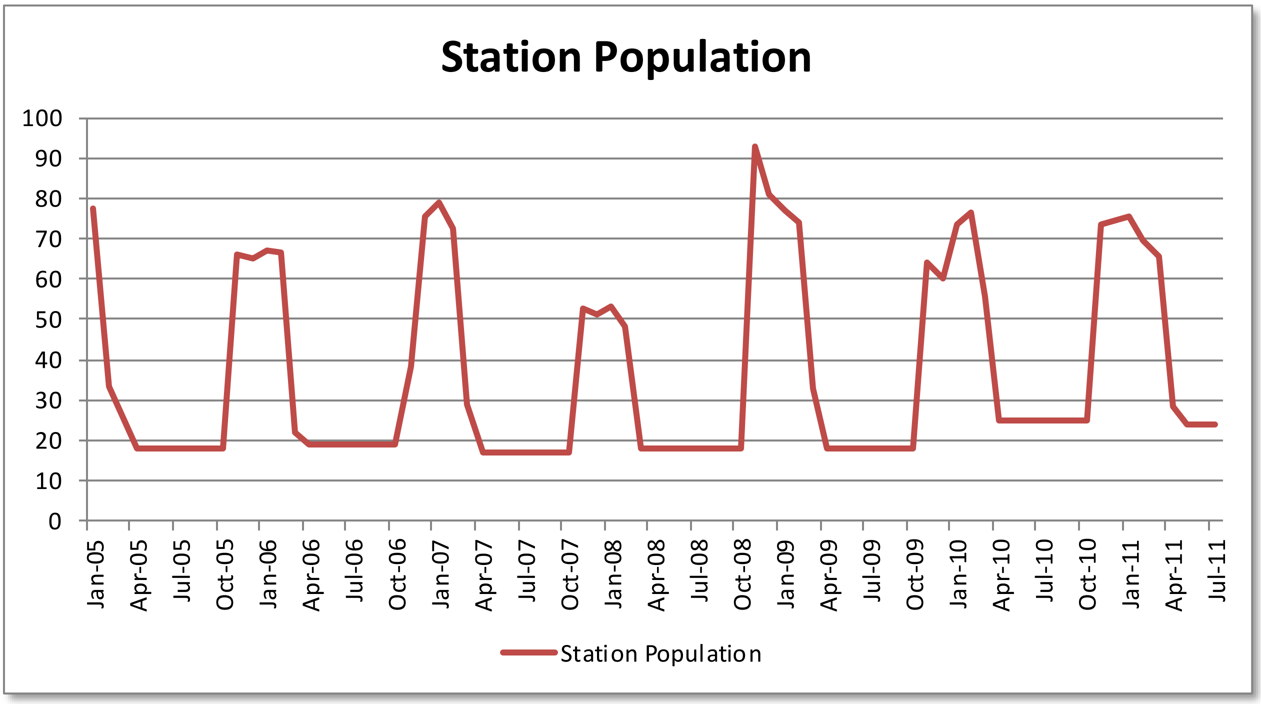
1.2.2 Flow Parameters

Due to the seasonal nature of the stations the plant must be designed to deal with large variations in flow. It is expected that over the whole range of inflow rates the plant will always operate within the quality parameters detailed elsewhere in this document. Davis Station population varies seasonally as detailed below:

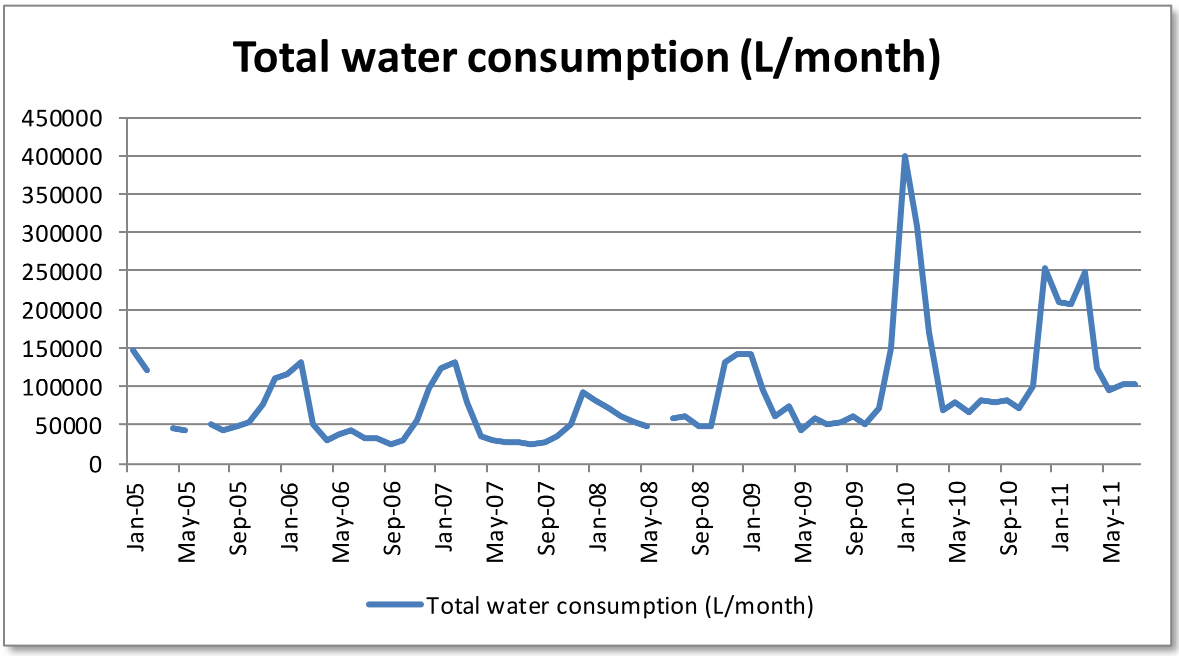
Station Population	Summer	Winter
Maximum	150	30
Average	120	25
Minimum	70	17

Note: Summer is approximately defined as being the six months from November to April inclusive, winter being the balance.

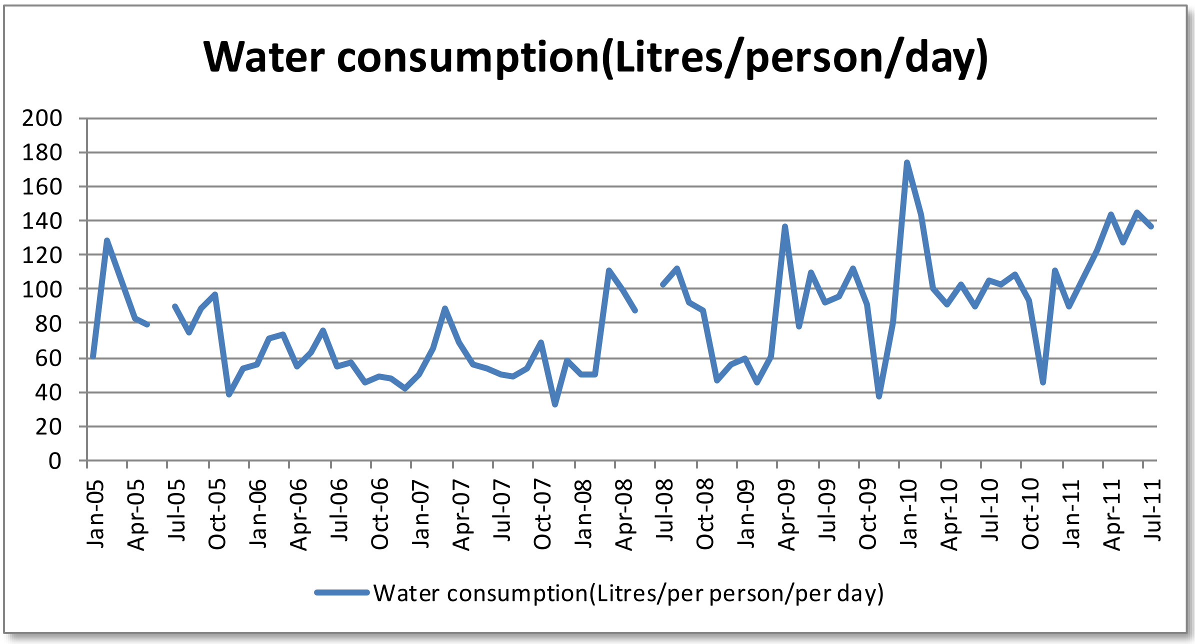
1. S. Fiona Barker, Michael Packer, Peter J. Scales, Stephen Gray, Ian Snape, Andrew J. Hamilton, Pathogen reduction requirements for direct potable reuse in Antarctica: Evaluating human health risks in small communities. Science of the Total Environment, 461-462 (2013) 723-733



In the absence of a flow meter on the outfall line there is no data available on the quantity of wastewater currently being discharged to the ocean. However, there is relatively accurate date on the use of potable water by the station – see below. Due to the nature of the station (closed system i.e. no groundwater/stormwater infiltration or losses except by evaporation) it is possible to use this data to make a reasonably good estimate of the load on the plant over time.



From this data it is possible to calculate the water consumption and therefore wastewater production per person per day. – see below.



From this it is possible to see a steady increase in personal use over time. This is largely due to improved availability of potable water and relaxed restriction as a result. Based on this data, a design figure of150 L/person/day should be used. It is expected that water use will be restricted at this level into the future.

Therefore the design values for the plant flow are as follows:

Maximum flow: 22.5kl/day
Minimum flow: 2.55kl/day

The daily diurnal flow profile is difficult to establish due to the lack of appropriate instrumentation and the nature of the system. Each source of wastewater has a holding tank which only pumps out to the sewer main when it reaches the high level. As a result there is very inconsistent influent flow that does not reliably conform to traditional models.

2. Process Unit Description

2.1 Process Unit No.1 – Ozonation

2.1.1 Purpose and Description

Ozonation has been applied in drinking water treatment as a disinfectant, to oxidize taste and odour compounds and TrOCs, and to increase the biodegradability of natural organic matter. As a disinfectant it is effective for virus and bacteria but less so for protozoa.

Ozone is generated in-situ by passing an electric discharge through a gas supply comprising clean dry air or oxygen. The resultant ozone is a very strong biocide and oxidising agent and is effective in reducing dissolved organics, pesticides & herbicides, many endocrine disrupting compounds, colour, iron, manganese, taste and odour. Furthermore, ozone will convert some of the non-biodegradable organics to biodegradable organic matter, which can be removed by the Biological Activated Carbon filter.

The effectiveness of an ozone system depends on the characteristics of the water, the ozone dose and the amount of time the microorganisms are exposed to the oxidant. Important considerations for effective ozone treatment are turbidity (less than 1 NTU), pH (between 6 - 8) and water temperature (determines minimum contact time to achieve LRV).

Ozonation may also produce bromates if brominated compounds are contained in the feed. Wastewater at Davis station is known to contain brominated fire retardants (polybrominanted diphenyl ethers: PBDE) (Australian Antarctic Division - Terrestrial and Nearshore Ecosystems Theme (Science Branch), 2011). The potential concentration of bromate produced if all the fire retardant was converted to bromate is estimated to be below the Australian Drinking Water Guideline values and rejection (66%) by reverse osmosis is also possible.

The ozone destructor takes the off-gas from the ozone contact tank and converts the residual ozone back to oxygen prior to release to the environment.

N-Nitrosodimethylamine (NDMA) may also be formed by ozonation, and NDMA may also pass through RO membranes into the permate. Control of NDMA production by ozone treatment and its removal downstream downstream by the BAC and RO systems will be the subject of trials at Selfs Point.

2.1.2 Design Parameters

Credible LRV achieved for Ozone system (Sources: AGRW, US EPA)

	Protozoa		Bacteria	Virus
Achievable	Giardia	Cryptosporidium	>4	>4
	>3	0		
Claimed	0		2	2

To achieve the claimed LRV for virus and bacteria, the largest required CT is for virus, therefore:

- CT_{calc} Value: 0.26 mg.min/L(at19°C, pH 6-8)

Selected from the (US EPA) LT2ESWTR Publication, 2009[2].

- Contact Tank Volume: 480 L

A volume of 480 L has been selected for the contact tank based on available space and various equipment supplier options.

- Theoretical Detention Time T_{10}: 4.9 minutes measured by Step Dose Method provided by US EPA *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual(2003)*

- Minimum Residual Ozone (C): 0.053 mg/L (@ 19°C)

Residual is calculated by rearranging the CT equation as follows:

$$CT_{calc} = C \times T$$

Where:

$$C = Residual\ Disinfectant\ Concentration (mg/lt)$$
$$T = Contact\ Time (minutes)$$

Therefore:

$$C = \frac{CT_{calc}}{T}$$
$$C = \frac{0.26}{40.9}$$
$$C = 0.053\ (mg/L)$$

- Minimum Ozone Dose(C_{init}): 9.68 mg/L

The ozone demand (C_{fd}) for secondary effluent in the first 2 min is about 0.5-9.6 mg/L (Xu et al. 2002[3]) based on three wastewater samples (2 x secondary and 1 x tertiary) from USA, France and UK. The ozone decay can be assumed as a first order decay after the initial fast consumption (Kim and Kim 2005[4]):

2 US EPA *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual*
3 *Xu, P., M.-L. Janex, Savoye, P., Cockx, A., Lazarova V. (2002) "Wastewater disinfection by ozone: main parameters for process design." Water Research* ***36****(4): 1043-1055.*
4 *Kim, D. and J.-H. Kim (2005). A Computer-based Design of New Ozone Contactor Treating Paldang Dam Reservior Water.*

$$\frac{dC}{dt} = -kC$$

The decay constant k is determined as follows (pH =7.0):

$$k = Aexp\left(-\frac{E_a}{RT}\right) = 0.0013\ s^{-1}$$

Where:

$$A = Frequencey\ Factor = 4111.7$$
$$E_a = Activation\ Energy\ = 36672.6\ J/mol$$
$$R = Ideal\ Gas\ Constant\ = 8.31 \frac{J}{mol \cdot K}$$
$$T = Absolute\ Temperature\ = 273.15 + 19 = 292.15K$$

Therefore by rearranging the first Order Decay equation gives:

$$\frac{dC}{C} = -kdt$$

And integrating between C_0 (Initial Ozone) and C (Minimum Ozone Residual):

$$\int_{C_0}^{C} \frac{dC}{C} = \int_0^t -kdt$$
$$ln \frac{C}{C_0} = -k(t-0)$$
$$ln \frac{C}{C_0} = -kt$$

Substituting the values in gives:

$$ln \frac{0.053}{C_0} = -0.0013 \times (4.9min \times 60sec)$$

And solving for C_0:

$$C_0 = \frac{0.053}{e^{-0.0013 \times 294}}$$
$$C_0 = 0.078\ mg/L$$

Therefore, the ozone transferred into the water should be the sum of the initial ozone from the first order decay plus the fast demand value. In the interests of conservatism, the largest ozone fast demand value was used:

$$C_{init} = C_0 + C_{fd} = 0.078 + 9.6 = 9.68\ mg/L$$

- Minimum Ozone Flow: 11.6 g/h

Based on the maximum plant design flow of 20L/min the required ozone flow is:

$$Ozone_{Flow} = C_{init} \times Flow$$
$$Ozone_{Flow} = 9.68\ (mg/L) \times 20(L/min) \times 60(min)$$
$$Ozone_{Flow} = 11.6(g/h)$$

- Capacity requirement for Ozone Unit: 17.4 g/h

Based on continuous operation of the plant at maximum design flow and variation of the feed water, 50% of safety margin is used

$$Ozone_{cap} = Ozone_{Flow} \times (1 + 50\%)$$
$$Ozone_{cap} = 17.4\ g/hour$$

The capacity of the purchased unit (Wedeco OCS – GSO 10) is 30 g/h ozone, which exceeds the minimum capacity required for this system.

2.1.3 Monitoring Systems

To ensure compliance the following monitoring systems are used:

- Ozone Dose – The ozone residual after the contact tank will be measured and used to adjust the dosing flow from the ozone generator.

- Water Temperature – the temperature of the water is measured and used to control the set CT by varying the setpoint ozone concentration.
- Ozone in atmosphere –ozone leaking will be monitored by an ozone detector and will trigger an alarm and shut down the ozone generator

2.2 Process Unit No.2 – Microfiltration (Ceramic Membranes)

2.2.1 Purpose and Description

Micro filtration provides a physical barrier to the passage of suspended solids and high molecular weight dissolved solids in water. Microfiltration is also effective at removal of bacteria and protozoa. Microfiltration uses a hydrostatic pressure to force water through a porous membrane, where solids are retained on the surface of the membrane.

The solids removal performance of microfiltration membranes is determined by the nominal pore size (measured in micron) and pore size distribution. Membrane performance is dictated by the fouling potential of the feedwater, membrane resistance and permeability.

The purpose of the micro filtration membranes will be to achieve a LRV of 4 for protozoa, and will provide additional LRV for bacteria and virus.

The compressed air system will be used for verification of membrane integrity via a pressure decay test, as well as for aeration for backwashing/cleaning. The backwash tank will be used to provide filtered water for backwashing of the membrane.

Credible LRVs for the Western Corridor Project

	Virus	Protozoa	Bacteria
LRV	0	3.5	3.5

2.2.2 Design Parameters

The following LRV credits are required from the MF system:

	Virus	Protozoa	Bacteria
Achievable	>4	>4	>4
Claimed	1	4	1

To achieve the required LRV, the following design parameters will be used:

- Pore size = 0.1 µm

For above pathogens, the size of bacteria is smaller than protozoa and is generally greater than 0.5 µm.

- Number of elements: 2

Only one module will be used for filtration, and the other module is in standby mode.

- Flux: 48 $Lm^{-2}h^{-1}$

$$Flux = \frac{Feed\ flow}{membrane\ area} = \frac{20}{25} = 0.8\ Lmin^{-1}m^{-2} = 48\ Lh^{-1}m^{-2}$$

- Maximum Recovery:

$$Recovery = 1 - \frac{backwash\ volume}{Flux \times membrane\ area \times 2\ hour} = 1 - \frac{100}{48 \times 25 \times 2} = 96\%$$

- Pressure of compressed air for integrity test: 1.2 bar

The pressure decay test is used to determine the integrity of membrane, and the direct integrity testing should be conducted on each membrane unit for each batch of water. For this system, a pressure decay test will be performed for every batch of water produced (ie for each chlorine detention tank of water), so that the integrity of the membrane is verified for each batch of water sent to the storage tank. The test pressure is determined by:

$$P_{test} = \frac{4\sigma\cos\theta}{d} + BP_{max}$$

If the maximum back pressure is 15 kPa in this case, assuming the worst case, contact angle θ = 0 degree, water at 5ºC so:

$$P_{test} = \frac{299.1}{d} + 15$$

To obtain a resolution of 3 µm, the P_{test} = 114.7 kPa = 120 kPa.

- Backwash frequency: 2 hours or the end of each batch.

The backwash comprises: fill the backwash tank with filtrate (100L) to 60% capacity, pressurise the backwash tank to 5 bar by compressed air, backwash from the filtrate side of the membrane to feed side, start the air scour (1 bar) on the feed side when the water level the backwash tank reaches 40%, shut off the backwash tank when the water level is about 10%, and continuously air scour the feed side for 1 min.

2.2.3 Monitoring Systems

- Membrane fouling is monitored by ensuring transmembrane pressure is less than 50 kPa[5].
- Direct membrane integrity testing: pressure decay test, decay reading of ≤0.49 kPa/min indicates an intact membrane.

The sensitivity of the direct integrity test can be determined by (USEPA):

$$LRV_{DIT} = log\left(\frac{Q_p \cdot ALRC \cdot P_{atm}}{\Delta P_{test} V_{sys} VCF}\right)$$

Where: $ALCR = \frac{527\Delta P_{eff}(175 - 2.71T + 0.0137T^2)}{TMP(460+T)}$ for the laminar flow (T, ºF).

$$\Delta P_{eff} = (P_{test} - BP)\left[\frac{(P_{test}+P_{atm})+(BP+P_{atm})}{2(BP+P_{atm})}\right]\left(\frac{BP+P_{atm}}{P_{atm}}\right) = 175.9\ kPa$$

so:

$$ALRC = 490$$

Since $LRV_{DIT} = 4$, $V_{sys} = 200\ L$ (based on half of the volume of the membrane), $Q_p = 20\ L/min$, $TMP = 20\ kPa$ and $VCF = 1$, the decay rate:

$$\Delta P_{test} = 0.49\ kPa/min$$

A pressure of 120 kPa is required for the test, and a pressure decay reading of ≤0.49 kPa/min will be required to ensure compliance with the required LRV of 4.

- Indirect membrane integrity test: turbidity - a maximum set point of 0.15 NTU (USEPA), and two consecutive filtrate turbidity readings above 0.15 NTU on any membrane unit trigger immediate direct integrity testing on that unit (USEPA).

5 *Lehman, S. G. and Liu, L. (2009). "Application of ceramic membranes with pre-ozonation for treatment of secondary wastewater effluent."* *Water Research* ***43****(7): 2020-2028.*

2.3 Process Unit No.3 – Biologically Activated Carbon Filter

2.3.1 Purpose and Description

No LRV credits are required from the BAC Filter, as its purpose is to enhance the removal of TrOCs, metals and Dissolved Organic Carbon (DOC), when used in combination with ozone. The primary aim will be to reduce Chemical of Concerns (CoCs) by using a combination of ozone and BAC.

BAC filters operate in two modes of treatment. In adsorption mode surface sites on the carbon physically adsorb a range of dissolved solids. In biological mode, bacteria which live in the pores of the carbon assimilate organic matter from the water in order to grow. The biological mode extends the life of an activated carbon filter considerably as bacteria are responsible for the removal of CoCs and DOC, and continuously grow on the carbon.

Fouling and headloss in BAC filters is controlled by air scour and backwashing.

2.3.2 Design Parameters

The following design parameters will be used:

- Empty Bed Contact Time (EBCT): 20minutes

A value of 20 minutes has been selected based on research that indicates that CoCs can be largely removed by a BACF in this timeframe[6].

- Filter Volume (V): 0.4m^3

At a plant design flow rate of 20L/hr the required volume to achieve the EBCT is calculated by rearranging the EBCT equation for Volume:

$$EBCT = \frac{V}{Volumetric\ Flowrate}$$
$$V = EBCT \times Volumetric\ Flowrate$$
$$V = 20 \times 20$$
$$V = 400L$$

- Media: Acticarb BAC GA1000N 8x30 Mesh

This media has been selected because it is specifically manufactured for BAC filter applications and consequently has the optimum pore size and features such as the characteristic fluted pore structure that is required to encourage biological growth. It is also readily available in Australia.

- Filter dimensions:0.5m x 0.8m x 1.65m (WxDxH)

Based on the physical constraints for the plant, a rectangular BAC footprint of 0.5m x 0.8m has been selected as being satisfactory. The bed depth can then calculated as follows[6]:

$$Volume = Area \times Bed\ Depth$$
$$Bed\ Depth = \frac{Volume}{Area}$$
$$Bed\ Depth = \frac{0.4}{0.5 \times 0.8}$$
$$Bed\ Depth = 1m$$

Allowing for the backwash bed expansion factor (see below) gives a bed depth of 1.3m.

A 150mm plenum height has been assumed at the bottom of the filter for take-off connections, air scour connections, etc. At the top an additional 200mm has been allowed for launders, inlet connection, etc. Therefore, the total height of the filter will be 1.65m.

- Bed expansion during backwash: 30%

6 A. S. Josson, R. Wimmerstedt, A. C. Harrysson, Membrane distillation - a theoretical study of evaporation through microporous membranes, Desalination. 56 (1985) 237-249.

A bed expansion of 30% has been selected as research indicates that bed expansion of less than 30% does not result in effective cleaning during backwash. Bed expansion of less than 30% during backwash results in some of the removed solids remaining in the media and contributing to increased headloss after the filter is returned to service.

- Backwash upflow velocity: 35m/hr

Based on the density of the media an upflow velocity of 35m/hr has been recommended by the supplier as being the optimum velocity to achieve the required bed expansion to wash out excess biological material.

- Backwash upflow: 3.3L/s

To achieve the required upflow velocity given the size of the filter the flow rate is calculated as follows:

$$Flow = Area \times Velocity$$
$$Flow = (0.5 \times 0.8) \times 30$$
$$Flow = 12m^3/hr$$
$$Flow = 3.3L/sec$$

- Backwash water volume: 2178L

Based on a backwash cycle that consists of 2 minutes of low rate backwash (50%) flow and 10 minutes of high rate backwash (100%) flow the total required volume of backwash water is:

$$Total\ Volume = [120sec \times 50\% \times 3.3L/sec] + [600sec \times 3.3L/\mathrm{sec}]$$
$$Total\ Volume = 2178L$$

Backwash water will be provided from the station potable supply via the cleaning system and will be returned to the station WWTP inlet.

- Air Scour upflow velocity: 40m/hr

Based on experience at simular plants an air velocity of 40m/hr is optimal for achieving effective solids removal from the media.

- Air Scour flow rate: 0.03m^3/minute (@10Bar, 19°C)

Using the same equation as for the water, the flow is as follows:

$$Flow = Area \times Velocity$$
$$Flow = (0.5 \times 0.8) \times 40$$
$$Flow = 16m^3/hr$$
$$Flow = 0.3m^3/\min(@101.3kPa)$$
$$Flow = 0.03m^3/min(@\ 10Bar)$$

- Air Scour Volume: 0.36m^3 (@10Bar, 19°C)

Based on a backwash cycle that consists of 10 minutes of air scour followed by 2 minutes of combined air scour and low rate backwash the total required volume of air is:

$$Total\ Volume = [10minutes \times 0.03m^3/min] + [2minutes \times 0.03m^3/min]$$
$$Total\ Volume = 0.36m^3(@10Bar, 19°C)$$

2.3.3 Monitoring Systems

The flow through the BAC filter determines the Empty Bed Contact Time (EBCT) for the filter media. The EBCT is important to know, as different CoCs have different removal rates for activated carbon. Ensuring sufficient EBCT will be essential for compliance of TrOC removal.

Turbidity can be used to identify issues with breakthrough of solids and sloughing of biological material from the BAC filter. The turbidity meter will have a setpoint maximum of 0.05 NTU.

Upstream and downstream pressure indicators will be used to determine differential pressure and hence headloss across the BAC filter. A backwash of the BAC filter will be triggered by either time (hours filtration) or by headloss (to be decided by the plant arrangement).

2.4 Process Unit No.4 – Reverse Osmosis

2.4.1 Purpose and Description

The phenomenon of osmosis occurs when pure water flows from a dilute saline solution through a membrane into a higher concentrated saline solution. If a force (pressure) is applied to the saline body of water, the direction of water flow through the membrane can be reversed. This is the basis of reverse osmosis. Note this reversed flow produces pure water from the salt solution, since the membrane is not permeable to salt. The RO unit will be used to reduce TDS, COCs and pathogens. The purpose of the mixing tank will be to provide a consistent feed salinity to the RO process to prevent sudden changes in osmotic pressure and/or flow across the RO membranes.

The RO pump will provide the driving force to overcome osmotic resistance across the membrane. A flushing and chemical cleaning system will be included as parts of the RO process to enable flushing of membranes with permeate as well as cleaning with biocide, acid and caustic to maintain membrane performance.

Credible LRVs for RO elsewhere in Australia

	Virus	Protozoa	Bacteria
Gippsland Water Factory	2	2	2
Western Corridor Project	2	2	2
GWRT, Perth	3	3	3

2.4.2 Design Parameters

The following LRV credits are required from the RO System:

	Protozoa	Bacteria	Virus
Achievable	>4	>4	>4
Claimed	2	1.5	1.5

- The designed feed raw water to the system is 20 L/min
- TDS is assumed to be 2033 mg/L
- Recovery to be 70%
- The modelling results from ROSA (the software provided by DOW for FILMTEC™) are listed:

System Details

Feed Flow to Stage 1	1.80 m^3/h	Pass 1 Permeate Flow	0.84 m^3/h	Osmotic Pressure:	
Raw Water Flow to System	1.20 m^3/h	Pass 1 Recovery	70.00 %	Feed	1.58 bar
Feed Pressure	16.61 bar	Feed Temperature	15.0 C	Concentrate	5.12 bar
Flow Factor	0.85	Feed TDS	2033.69 mg/l	Average	3.35 bar
Chem. Dose	None	Number of Elements	5	Average NDP	11.46 bar
Total Active Area	36.23 M^2	Average Pass 1 Flux	23.18 lmh	Power	1.04 kW
				Specific Energy	1.24 kWh/m^3

Water Classification: Wastewater with DOW Ultrafiltration, SDI < 2. 5

Stage	Element	#PV	Ele	Feed Flow (m^3/h)	Feed Press (bar)	Recirc Flow (m^3/h)	Conc Flow (m^3/h)	Conc Press (bar)	Perm Flow (m^3/h)	Avg Flux (lmh)	Perm Press (bar)	Boost Press (bar)	Perm TDS (mg/l)
1	BW30-4040	1	1	1.80	16.27	0.60	1.60	16.10	0.20	27.21	0.00	0.00	17.46
2	BW30-4040	1	1	1.60	15.76	0.00	1.42	15.62	0.18	25.32	0.00	0.00	21.06
3	BW30-4040	1	1	1.42	15.27	0.00	1.25	15.16	0.17	23.33	0.00	0.00	25.74
4	BW30-4040	1	1	1.25	14.81	0.00	1.10	14.72	0.15	21.17	0.00	0.00	32.01
5	BW30-4040	1	1	1.10	14.37	0.00	0.96	14.30	0.14	18.88	0.00	0.00	40.50

- The mixing/feed tank will have a volume of 400 L. The permeate buffer tank will hold 200 L. This is sufficient for the membranes to be flushed for a period of 5 min at 20 L/min. During operation the rate of filling of the permeate buffer tank will be 14 L/min, requiring 15 mins runtime to fill. The cleaning chemical tank will hold up to 200L of batched chemicals.

2.4.3 Monitoring Systems

- The feedwater and permeate flow can be used to determine the recovery of the RO process. The design recovery for this process is 70%.
- Pressure indicators can be used to determine the differential pressure across the membranes. This provides an indication of membrane fouling.
- The conductivity analysers are used to monitor the membrane integrity and determine at least 1 LRV for bacteria and virus.
- PDT will be used to achieve 2 credible LRV for protozoa.
- On-line chemical oxygen demand (COD) sensors may also be installed to provide a means to detect variations in organic carbon passing the RO membrane. Such signals may also identify periods where COCs concentrations vary in the RO permeate. Installation of the COD sensors is reliant on accessing these sensors via a grant.
- The PDT will be recorded by the PLC as will the conductivity measurements required to confirm the 1 LRV for virus and bacteria.

2.4.4 Cleaning Strategy (DOW's manual, 2008).

1. The concentrate will be flushed out with permeate upon shutdown of the RO.

2. RO membrane will be cleaned when one or more of the below mentioned parameters are applicable:
   The normalized permeate flow (flux/driving pressure) drops by 10%
   The normalized salt passage increases by 5 - 10%
   The normalized pressure drop (feed pressure minus concentrate pressure) increases by 10 - 15%

3. Cleaning Pump and Process parameters
   Pump should be constructed of 316 SS or non-metallic composite
   Cleaning pressure: 1.5-4.0 bar (depending on the resistance of the RO elements)
   Cleaning temperature:
   Alkaline cleaning < 45ºC
   Acid cleaning < 45ºC

4. Cleaning Chemicals
   Alkaline: 0.6 wt% NaOH (pH 12)
   Acid: 0.55 wt% HCL (pH 2)
   Soak time: acid 30 min, alkaline 60 min
   Circulation time: 30 min
   Soak flow rate: 0.3 m^3/h
   Flush rate 2.7 – 3.2 m^3/h
   Flush

2.5 Process Unit No.5 – Ultra Violet Disinfection

2.5.1 Purpose and Description

The Ultra Violet Light Disinfection Process Unit is a non-chemical process whereby pathogens contained in water are exposed a dose of ultraviolet radiation near the peak of germicidal effectiveness, being 250 to 270 nanometres (nm). This exposure results in the deactivation of the DNA or RNA of the pathogen, rendering it unable to reproduce.

The effectiveness of a UV disinfection system depends on the characteristics of the waste being disinfected, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration. For any treatment plant, disinfection success is directly related to the concentration of colloidal and particulate constituents in the wastewater as these may act to shield pathogens from UV radiation.

Credible LRV for UV elsewhere in Australia

	Protozoa	Bacteria	Virus
Victor Harbor (@36mJ/cm^2)	1.5	2	0
Western Corridor Project (Advanced oxidation incorporating H_2O_2- UV)	4	4	4
Ground Water Replenishment Trial (GWRT), Perth (Advanced oxidation incorporating H_2O_2- UV)	4	4	4

2.5.2 Design Parameters

The following LRV credits are required from the UV System:

	Protozoa	Bacteria	Virus
Achievable	>4	>4	>4
Claimed	4	4	4

To achieve the required LRV the following design parameters will be used:

- Dosing value: 186 mJ/cm^2

This value is selected from the USEPA ultraviolet disinfection guidance manual (2006) as being the value required to achieve a LVR of 4 for viruses.

- Number of UV reactors: 1

For redundancy it has been decided that the system will use two independent reactors in series, any one of which will be capable of providing sufficient energy to meet the requirements herein. Therefore, all calculations will be done on the basis of two reactors. The second reactor will allow for a batch to be completed in the event of a failure of the other reactor, without compromising the LRV credits of the system.

- Contactor volume: 19L

Based on supplier data the UV reactors have an approximate effective volume of 19 Litres.

- Detention Time: 114sec

The Detention Time is calculated by:

$$Detention\ Time = \frac{Volume}{Flow}$$

A worst case flow of 20L/min is used. In reality the flow will always be less than this as a percentage of the flow will be lost as brine in the proceeding RO stage.

$$Detention\ Time = \frac{19L}{20L/min}$$
$$Detention\ Time = 57sec$$

- Required UV-C (254nm) minimum output: 21.8 W

The UV-C intensity (irradiance) at the reactor surface can be calculated as follows:

$$Dose\ \left(\frac{mJ}{cm^2}\right) = Transmitted\ Intensity(mW/cm^2)\ \times Detention\ time(s)$$

Substituting and rearranging from previous results gives:

$$Transmitted\ Intensity = \frac{186}{57}$$
$$Transmitted\ Intensity = 3.26\,mW/cm^2$$

Required power is then calculated as:

$$Power(W) = Transmitted\ Intensity\,(W/m^2) \times Area(m^2)$$

Based on supplier data the dimensions of the reactor result in an internal surface area of 2205 cm^2, therefore the total required power is:

$$Power(W) = 0.00326 \times 2205$$
$$Power = 7.2W$$

Assuming the lamp is in centre of the reactor and the transmittance of the water (RO permeate by this stage) is greater than 0.95 cm^{-1}, then over the 8 cm distance from the lamp to the wall the total power reduction ratio will be:

$$P_{reduction} = 0.95^8$$
$$P_{reduction} = 0.66$$

Therefore, the required UV-C output (@254 nm) will be:

$$UV - C_{output} = \frac{7.2}{0.66} = 10.9\,W$$

2.5.3 Monitoring Systems

- The flow through the UV system will be monitored in order to determine the residence time for UV disinfection.
- The UV intensity measurement is defined as the overall power of the lamp (energy per unit surface area). Also called power density, intensity refers to total lamp output.
- The UV dose is required to determine the LRV of the UV system. UV dose is defined as the product of UV intensity and residence time:

  Dose = I x T

UV dose is dependent upon the specific application, taking into account water quality, arc tube ageing, industry specifications, as well as microbiological standards.

UV Transmittance (UVT), expressed in % cm^{-1}, is the measure of UV light energy available to treat the water. The higher the % value the greater the UV dose will be. UV light absorbed by substances in water will not be available for inactivation of pathogens. Specifying UV dose accurately is not possible without measurement of UVT. The UV temperature sensor measures the temperature inside the electrical cabinet to ensure sensitive electrical components do not overheat.

The UV intensity will be recorded by the PLC.

2.6 Process Unit No. 6 – Calcite Contactor

A commercially available calcite filter Puretec® NTS2000 was used in the built plant. Its dimensions are slightly smaller to those specified by the design. The rated flowrate claimed by the manufacturer is 20 L/min.

2.6.1 Purpose and Description

The RO permeate is low in ion content and alkalinity, which is not suitable for drinking and corrosive to the water distribution system. The calcite filter can effectively solve this issue without undue risk of overdose.

$$CaCO_3 + CO_2 + H_2O \leftrightarrows Ca^{2+} + 2HCO_3^-$$

As shown in the above equation, the dissolution of $CaCO_3$ is determined by the pH and dissolved CO_2.

2.6.2 Design parameters

pH	Ca^{2+} (mg/L)
7-8.5	>20

To achieve the design parameters, based on Hernández-Suárez 2005[7], the EBCT required for the calcite filter is 4.1 min, the linear velocity is 0.32-0.37 m/min.

- Volume of the filter is 85 L and the height is 1.6 m

$$Volume_{filter} = flowrate \times EBCT = 20\ L/min \times 4.1min = 82\ lt$$
$$Height_{filter} = Flow\ velocity \times EBCT = 0.37\ m/min \times 4.1min = 1.52\ m$$

- Annual consumption is greater than 260 kg. Under above conditions, the Ca^{2+} concentration is 26.3 mg/L. Based on the average population in the station (120 in summer and 25 in winter), the total water supply annually is 3,915 m^3. Therefore, the $CaCO_3$ (99% purity, not Ca^{2+})

$$Consumption_{CaCO_3} > 26.3 \times \left(\frac{100}{40}\right) mg/L \times 3915\ kL/min\ /0.99 = 260\ kg$$

- The total limestone in the filter is 127.8 kg.
  The density of the 2-2.5 mm limestone is 1.5 kg/L.

$$Weight_{limestone} = Density \times Volume_{filter} = 1.5kg/L \times 85\ L = 127.8\ kg$$

- Top up duration: The filter will need to be topped up after processing a volume of 648 m^3 (in summer, 36 days).
  Assuming the filter needs to be topped up, when 1/3 of the calcite is consumed.

$$Duration = \frac{\frac{1}{3}Weight_{limestone}}{120 \times 150L \times 26.3\frac{mg}{L} \times \left(\frac{100}{40}\right)} = 36days$$
$$Volume = \frac{1}{3}Weight_{limestone}/(26.3\ mg/L \times (100/40)\ ) = 648\ m^3$$

2.6.3 Monitoring Systems

To ensure compliance the following monitoring systems are used:

- Top-up duration. Total volume of water processed will be measured and recorded by PLC.
- Water pH Value via pH sensor (L3188)

7 *Hernández-Suárez, M. (2005). Short Guideline for Limestone Contactor Design for Large Desalination Plants, Canary Islands Water Center.*

2.7 Process Unit No.7 – Chlorination

2.7.1 Purpose and Description

Chlorine is one of the most widely used disinfectants. It is very effective for the deactivation of pathogenic microorganisms. Chlorine can be easily dosed, measured and controlled. Chlorine residuals are fairly persistent and chlorination is relatively cheap.

The purpose of the chlorine system will be to provide final disinfection of the product water.

Credible LRV achieved for Chlorine Disinfection systems elsewhere in Australia

	Protozoa	Bacteria	Virus
Victor Harbor	No Credit	No Credit	3
Western Corridor Project	0	2	2
Gippsland Water Factory	No Credit	No Credit	4

In the interests of not having to transport and handle Dangerous Good in the form of various chlorine products (i.e. chlorine gas, etc), sodium hypochlorite will be stored and dosed at a metered rate via a static mixer to the process as required.

To achieve an effective kill of pathogens, a minimum contact time must be guaranteed with a minimum measureable residual chlorine quantity remaining afterwards. To achieve this, chlorine is mixed with the product water at a flow-paced concentration and then held in a contact tank for the calculated contact time. Once the contact time has expired the residual chlorine is measured and if it is greater than the critical control point requirement the water will be discharged to the customer, otherwise the water will be recycled to the beginning of the advanced treatment process.

To allow the plant to operate continuously there will be two contact tanks that will alternate between filling, contact time and discharging.

2.7.2 Design Parameters

The following LRV credits are required from the Chlorine Disinfection System:

	Protozoa	Bacteria	Virus
Achievable	0	>4	>4
Claimed	0	4	4

To achieve the required LRV the following design parameters will be used:

- CT_{calc} minimum required value is in range of 6-16 depending on the pH (≥ 10°C, pH ≤8.5) (Selected from 'Guideline for Validating treatment process for pathogen reduction, Supporting Class A recycled water scheme in Victoria', February 2013)
- Contact Tank Volume: $1m^3$

Two contact tanks A and B will be used on site. A volume of 1000L has been selected for the contact tanks based on the available space and the practical limitations around tank switching, etc.

The control strategy for the contact tanks: filling water into contact tank A, switching to tank B when tank A reaching 100% level, quickly discharging tank A as the level of tank B reaches 50%, and switching to tank A when tank B reaches 100% level.

- Theoretical Detention Time: 30 minutes

The contact time is decided by filling time minus the discharge time.

$$TDT = \frac{V}{Q_1} - \frac{V}{Q_2}$$
$$V = Volume\,(lt)$$
$$Q_1 = Peak\ Flow\,(L/minute)$$
$$Q_2 = Discharge\ Flow\,(L/minute)$$
$$TDT = \frac{800}{14} - \frac{800}{75}\,TDT = 46minutes$$

However, a TDT of 30 minutes will be used for design purposes as time will be required for switching valves.

- Baffle Factor (BF): 1

The Baffle Factor has been selected in accordance with the US EPA *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual(2003)*. Due to the design of the system: i.e. the chlorine is mixed inline before the contact tank (using a static mixer) and the chlorinated water is held in the contact tanks rather than allowed to flow through them (effectively perfect plug flow), a Baffle Factor of 1.0 could reasonably be assumed as there is no possibility of bypassing or short circuiting. However, for design purposes a Baffle Factor of 0.7 will be used.

- Contact Time (T): 30 minutes

Contact Time (T) is calculated by:

$$T = TDT \times BF$$
$$T = 30 \times 1$$
$$T = 30\ minutes$$

- Minimum Residual Chlorine (C): 0.2 – 0.53 mg/L (@ 19°C, pH6-9)

Residual is calculated by rearranging the CT equation as follows:

$$CT_{calc} = C \times T$$

Where:

$$C = Residual\ Disinfectant\ Concentration\,(mg/lt)$$
$$T = Contact\ Time\,(minutes)$$

Therefore:

$$C = \frac{CT_{calc}}{T}$$

CT_{calc} is in the range of 6-16:

$$C = 0.2 - 0.53\ (mg/L)$$

- Minimum NaClO Dose(C_{init}): 0.7 mg/L

Based on the likely characteristics of the water, the chlorine concentration is expected to decay according to the following[8]:

$$C = C_{init}e^{-Kst}$$

Where:

$$Ks = Decay\ Constant\ = 0.011\ (hour^{-1})$$

Rearranging for C_{init} based on the maximum theoretical residual gives:

$$C_{init} = \frac{C}{e^{-Kst}}$$
$$C_{init} = 0.54\ (mg/L)$$

For conservation design 50% safety margin is given and convert to NaClO:

$$C_{dosing} = C_{init} \times 1.5 \times 1.05 = 0.9\ (\frac{mg}{L})$$

- NaClO Flow: 14 mg/minute

8D. Gang, T. Clevenger, S. Banerji, Modeling chlorine decay in surface w ater, Journal of Environmental Informatics. 1 (2003) 21-27.

Based on the maximum plant design flow of 20 L/min the required chlorine flow is:

$$Cl_{Flow} = C \times Flow$$
$$Cl_{Flow} = 0.9 \times 14$$
$$Cl_{Flow} = 13\ (mg/minute)$$

- Daily Chlorine Gas Equivalent Volume: 28.8 g daily

Based on continuous operation of the plant at maximum design flow, the required daily Chlorine gas equivalent (CG_{equiv}) volume that will need to be produced is calculated by:

$$CG_{equiv} = Cl_{Flow} \times 60\ minute \times 24 hours$$
$$CG_{equiv} = 19\ g/day$$

2.7.3 Monitoring Systems

To ensure compliance the following monitoring systems are used:

- Chlorine Dose – The chlorine concentration in the water directly after the static mixer will be measure and used to adjust the dosing pump flow rate to ensure that the minimum Chlorine dose is always maintained.
- Water pH Value – the pH of the water is measured prior to mixing with Chlorine. This is used to adjust the contact time.
- Water Temperature – the temperature of the water is measured and used to adjust the contact time.