Solo Water

Appendix 4.2.10 **Non Potable Water Preliminary Risk Assessment**

Project: Catherine Hill Bay Water Utility
Client: Rose Group
Title: Non-Potable Water Preliminary Risk Assessment for IPART Application
Author: BI
Date (Revision): 10/07/2013 (Revision B)
Risk Criteria: As per Tables 2.5, 2.6 & 2.7: Australian Guidelines for Water Recycling: Managing Health and Environmental Risks-phase 1 (2006)

Scheme Component	Hazard	Hazardous Event	Impact	Unmitigated Risk					Control Strategy	Mitigated Risk				
				Likelihood		Consequence		Risk		Likelihood		Consequence		Risk
MBR treated source water	Trace contaminants in MBR effluent feed water	Trace contaminants following MBR treatment	Potential impacts on recycled water uses	C	Possible	2	Minor	Moderate	1. Majority residential catchment hence there is a low likelihood of significant trace contaminants being present in recycled water. Refer to sewerage wastewater generation risk assessment table. 2. Customer supply contracts, recycled water use agreements and ongoing awareness and education through information provided with rates notices and via the CHB Water Utility Website. 3. Detailed annual recycled water quality monitoring for trace contaminants. 4. If contaminants are detected a source control investigation will be undertaken through analysis of trade waste and raw wastewater data. 5. If required additional treatment will be provided in the AWTP using reverse osmosis, activated carbon or ion exchange.	B	Unlikely	2	Minor	Low
	Poor water quality from MBR	MBR blower failure, shock loads, membrane failure etc	Poor quality feed water to AWTP	D	Likely	3	Moderate	High	1. Continuous online monitoring and alarms on critical MBR process parameters MLSS, DO, Permeate Turbidity, UV Intensity, transmembrane pressure. 2. Shut down AWTP if MBR produces poor quality effluent.	B	Unlikely	2	Minor	Low
Wet weather storage dam	Contamination of wet weather storage	Contaminants in wet weather storage going to AWTP during high demand	Poor quality feed water to AWTP	D	Likely	3	Moderate	High	During certain high demand situations the AWTP will take water from the wet weather storage. 1. Regular inspection for evidence of vermin access, e.g. mosquito larvae, bird nests etc or early detection of algae outbreaks. 2. UF prefilter on supply line from wet weather storage into AWTP. 3. Emergency response plan for algae outbreak which will include chemical treatment and/or aeration/mixing of pond. 4. If contamination detected, shut off supply from wet weather storage to AWTP. Note: Potable water top up available if recycled water storage tank levels get too low.	B	Unlikely	3	Moderate	Moderate
Advanced Water Treatment Plant	Pathogen break through from UF membranes	Rupture of membrane fibres	Non-compliant recycled water	D	Likely	4	Major	Very high	1. Use USEPA accredited ultrafiltration membranes. 2. Membrane integrity testing by air pressure decay as per manufacturer requirements. 3. Continuous online monitoring of UF permeate turbidity with alarms and automatic shutdown. 4. Continuous online monitoring and alarms on transmembrane pressure. 5. High quality MBR permeate as feed water. 6. Membrane chemical cleaning in line with manufacturer requirements to maximise membrane life. 7. Design flux, TMP and other process parameters as per manufacturer recommendations to maximise membrane life.	B	Unlikely	4	Major	High
	Inadequate pathogen inactivation due to low UV dose	Inadequate UV dose caused by lamp failure, reactor fouling, high flow, poor feed water quality	Non-compliant recycled water	D	Likely	4	Major	Very high	1. Use USEPA accredited UV disinfection system. 2. Continuous online monitoring of UV intensity and UV lamp faults with alarms and automatic shutdown. 3. Continuous online monitoring of flow through the UV reactor with alarms and automatic shutdown. 4. UV unit to include self cleaning functions. 5. Design and operation of UV unit as per manufacturer recommendations. 6. Replace UV lamps every 12 months.	B	Unlikely	4	Major	High
	Inadequate pathogen die off due to low CT in chlorine contact tank	Inadequate CT due to low chlorine concentration, high flow, low level in CCT, high COD, high temperature, incorrect pH	Non-compliant recycled water	D	Likely	4	Major	Very high	1. Chlorine contact tank designed to USEPA standards. 2. Continuous online monitoring of free chlorine residual and pH at outlet of the CCT with alarms and automatic shutdown. 3. Continuous online monitoring of flow and water level in the CCT with alarms and automatic shutdown.	B	Unlikely	4	Major	High
	High salt concentration	High salt concentration in feed water	Non-compliant recycled water	C	Possible	2	Minor	Moderate	1. Continuous online monitoring and control of EC/TDS in blended product water. The ratio of UF permeate diverted to the RO automatically increases as feed water EC/TDS increases. 2. Continuous online monitoring of feed water MBR permeate EC/TDS with alarms. 3. If there is persistent high TDS in MBR permeate feed water then a source control investigation will be undertaken through review of catchment raw wastewater quality and trade waste data.	B	Unlikely	2	Minor	Low
	Process chemicals	Spillage of chemicals used in the AWTP process	Potential OH&S and public health impacts. Potential environmental impacts in receiving environment	D	Likely	3		High	1. Appropriate bunding and separation in chemical storage and delivery areas. 2. Standard operating procedures to be developed for use of all chemicals. 3. MSDS of all chemicals maintained onsite. 4. Emergency Response Plan for chemical spillages.	B	Unlikely	2	Minor	Low

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Scheme Component	Hazard	Hazardous Event	Impact	Unmitigated Risk					Control Strategy	Mitigated Risk				
				Likelihood		Consequence		Risk		Likelihood		Consequence		Risk
Advanced Water Treatment Plant continued…	Metals, organic chemicals and other potential trace contaminants.	Presence of excessive amounts of metals, organic chemicals and other trace contaminants in treated water	Potential OH&S, public health and environmental impacts.	C	Possible	2	Minor	Moderate	1. Prevention strategy based around Trade Waste Agreements, Residential Supply Agreements, ongoing awareness and education at each billing cycle. 2. Predominately residential catchment, hence the likelihood of significant levels of contaminants is low. 3. Detailed annual monitoring of treated recycled water quality for trace contaminants at NATA laboratory. 4. If contaminants are detected a source control investigation will be undertaken through review of catchment raw wastewater and trade waste data. 5. If required additional treatment will be provided in the AWTP through activated additional RO treatment, carbon adsorption and/or ion exchange processes.	C	Possible	2	Minor	Moderate
	UF membrane chemical cleaning wastewater or UV acid clean wastewater	Management of chemical contaminated wastewater	Potential impacts on the MBR treatment process if inappropriately managed	E	Almost certain	4	Major	Very high	1. Temporary storage or all chemical contaminated wastewater from UF membrane and/or UV disinfection unit cleaning. 2. Neutralisation of all chemical contaminated wastewater before controlled trickle feed back to the MBR inlet balance tank. 3. If process impacts are observed on the MBR then offsite disposal of chemical wastewater will be undertaken by licensed waste contractor.	C	Possible	3	Moderate	High
Non-Potable Water Storage Tank	Vector borne diseases	Vermin or mosquito access to recycled water storage tank	Non-compliant recycled water	E	Almost certain	3	Moderate	High	1. Storage tank constructed to potable water standards with mosquito screens on all tank openings and overflows. 2. Regular monitoring and inspection for evidence of vermin or mosquito access. 3. If observed contaminated water will be wasted or if appropriate chemical treatment of the storage will be undertaken by addition of chlorine tablets, hydrogen peroxide or similar.	B	Unlikely	3	Moderate	Moderate
	Overflows	Tank overflow due to failure of level controls	Overflow to the environment	C	Possible	2	Minor	Moderate	1. Storage tank overflows directly to the wet weather storage or inlet balance tank.	B	Unlikely	1	Insignificant	Low
	Decay of free chlorine residual during storage	Loss of adequate free chlorine residual due to equipment failure, high temperature, long detention time or high COD	Non-compliant recycled water	D	Likely	3	Moderate	High	1. Recirculation system with free chlorine monitoring and sodium hypochlorite dosing and alarms on the recycled water storage tank. 2. If required chlorine tablets can be manually applied to the storage.	B	Unlikely	3	Moderate	Moderate
	Blue green algae	Blue green algae growth in non-potable water storage tank	Non-compliant recycled water	B	Unlikely	2	Minor	Low	1. Storage tank covered to prevent sunlight access and algae growth. 2. Regular inspection and monitoring of non-potable water storage tank.	A	Rare	2	Minor	Low
	Unintended contact with recycled water in storage	Human access to storage	Potential public health impacts	D	Likely	2	Minor	Moderate	1. Storage located inside the fenced and secure WWTP site. 2. Warning signage around the perimeter of the site and on each storage tank. 3. CCTV recording at the WWTP site. 4. Lockable manhole access points.	B	Unlikely	2	Minor	Low
	Tank failure	Tank failure	Flooding, contamination of surface water	C	Possible	2	Minor	Moderate	1. Tank constructed from steel panel tanks with civil/structural engineer certification for tank and footings. 2. Quality assurance in construction. 3. Bollard fence around tanks if there is a risk of vehicular or machinery damage.	B	Unlikely	2	Minor	Low
	Tank materials	Dissolution of trace metals into recycled water	Non-compliant recycled water	C	Possible	2	Minor	Moderate	1. Ensure all tank materials are compatible for use with potable water. 2. Metallic tanks to be lined with a food grade polymer liner to avoid dissolution of metals.	A	Rare	2	Minor	Low
Non-Potable Water Supply System	Cross connections	Cross connection with the CHB Water Utility potable water network	Contamination of potable water supply for up to 470 ET	D	Likely	4	Major	Very high	1. Only approved contractors or staff that have undergone CHB Water Utility induction can perform work on water utility infrastructure. 2. Potable and non-potable reticulation networks to be designed, constructed and tested in accordance with WSAA standards. 3. Water pressure in non-potable network to be maintained a minimum of 50 kPa below pressure in the potable network. 4. Quality assurance, inspection and pressure testing during construction. 5. Ongoing monitoring of water pressure and electrical conductivity in both networks during operation to assist with detection of cross connections. 6. Unique pipe materials in each water network. Potable network will use blue PVC and the non-potable will use lilac striped HDPE pipe. 7. Minimum pipe separation distances to be maintained in common trenches. Potable water pipework to be located above non-potable water pipework. 8. Identification tape and signage on all trenches. 9. Potable water is used in the non-potable water network until Stage 2 when the AWTP is constructed. Compliance audits will be undertaken prior to introducing recycled water to the network. 10. Conservative AWTP log reduction targets based on Table 3.7 in AGWR (2006).	B	Unlikely	4	Major	High

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Scheme Component	Hazard	Hazardous Event	Impact	Unmitigated Risk					Control Strategy	Mitigated Risk				
				Likelihood		Consequence		Risk		Likelihood		Consequence		Risk
Non-Potable Water Supply System continued…	Cross connections continued…	Cross connection with potable water line on private property	Potential use of non-potable water for potable uses inside the affected property (up to say 6 EP)	D	Likely	3	Moderate	High	1. All plumbing work on private property to be undertaken by Licensed plumber in compliance with AS3500 and the NSW Plumbing Code. 2. Plumbing inspection during house construction. 3. Dual check valve to be located at the potable water connection point for each property. 4. Residential Customer Supply Contracts outlining responsibilities under the scheme. 5. Ongoing customer awareness and education with information provided at each billing cycle and on the CHB Water Utility website. 6. Conservative AWTP log reduction target based on Table 3.7 in AGWR (2006).	C	Possible	3	Moderate	High
	Unintended or inappropriate uses of recycled water	Unintended uses of recycled water like swimming pool top up, drinking from outdoor taps, ingestion from excessive spray drift etc	Potential use of non-potable water for potable uses	E	Almost certain	3	Moderate	High	1. Residential customer supply contracts and recycled water use agreements. 2. Ongoing awareness and education with information provided at each billing cycle and on the CHB Water Utility website. 3. Appropriate identification and signage to be installed by plumbing contractor and verified during construction and plumbing inspection. 4. Appropriate pricing levels so non-potable water is not significantly lower in cost than potable water. 5. Flow monitoring to detect larger than normal flows 6. Conservative AWTP log reduction targets based on Table 3.7 in AGWR (2006).	B	Unlikely	3	Moderate	Moderate
	Loss of chlorine residual	Loss of chlorine residual due to long detention time, high temperature, high COD	Non-compliant recycled water	D	Likely	3	Moderate	High	1. Chlorine dosing regime will be calibrated for each season to ensure the minimum required free chlorine residual is maintained at the furthest point in the reticulation system. 2. Weekly monitoring of free chlorine throughout the reticulation system and in select private dwellings.	B	Unlikely	3	Moderate	Moderate
	Pipe breakage	Pipe breakage due to excavation or machinery that leads to surface runoff of recycled water	Potential contamination of surface waters	C	Possible	2	Minor	Moderate	1. PN16 HDPE pipe with welded joints and fittings. 2. Quality assurance and pressure testing during construction. 3. Above ground signage and identification tape in all trenches. 4. Register all work as executed plans with dial before you dig service and on the CHB Water Utility GIS. 5. Pressure and flow monitoring in the network to assist with detecting pipe breaks. 6. Visual inspection for wet, green, boggy areas or signs of soil erosion. 7. Customer fault reporting and response procedures in customer service. 8. Emergency Response Plan for main breaks. 9. All stormwater at the site is treated using bioretention basins in the stormwater treatment train.	B	Unlikely	2	Minor	Low
	Minor pipe leaks	Minor leaks from pipe joints and fittings	Potential contamination of groundwater	D	Likely	2	Minor	Moderate	1. PN16 HDPE pipe with welded joints and fittings. 2. Quality assurance and pressure testing during construction. 3. Visual inspection for green, wet and boggy areas. 4. Monitor flows throughout the network to identify water losses. 5. Use leak detection systems if required.	B	Unlikely	2	Minor	Low
Indoor uses on private lots for toilet flushing and washing machine cold water	Pathogens	Unintended uses	Potential public health impacts	E	Almost certain	3	Moderate	High	1. Class A+ recycled water with conservative log reduction targets. 2. Laundry washing machine cold water supply to be hard plumbed. 3. Residential customer supply contracts and recycled water use agreements. 4. Ongoing awareness and education with information provided at each billing cycle and on the CHB Water Utility website. 5. Appropriate identification and signage to be installed by plumbing contractor and verified during construction and plumbing inspection. 6. Appropriate pricing levels so non-potable water is not significantly lower in cost than potable water. 7. Flow monitoring to detect larger than normal flows.	B	Unlikely	3	Moderate	Moderate
Uncontrolled outdoor non-potable uses on private lots, i.e. irrigation and washdown	Pathogens	Human contact and ingestion of spray drift or surface runoff	Potential public health impacts	C	Possible	2	Minor	Moderate	1. Conservative AWTP log reduction target based on Table 3.7 in AGWR (2006). 2. Customer supply contracts, recycled water use agreements and ongoing customer education and awareness.	B	Unlikely	1	Insignificant	Low
	Nutrients	Excessive nutrient loads in irrigation	Potential contamination of soil and groundwater	C	Possible	2	Minor	Moderate	1. AWTP treated recycled water contains low nutrients of TN<7 mg/L & TP<0.25 mg/L and under normal irrigation rates and recycled water availability should not result in excessive nutrient impacts. 2. Detailed soil monitoring will be undertaken annually on private land on the 3 biggest users of non-potable water in the scheme based on customer non-potable water meter readings. 3. If required customers will be advised to reduce irrigation rates or other management measure as per the recycled water supply agreement.	B	Unlikely	2	Minor	Low

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Scheme Component	Hazard	Hazardous Event	Impact	Unmitigated Risk					Control Strategy	Mitigated Risk				
				Likelihood		Consequence		Risk		Likelihood		Consequence		Risk
Uncontrolled outdoor non-potable uses on private lots, i.e. irrigation and washdown continued…	Salinity	Irrigation with high salt recycled water	Reduction in plant growth and poor appearance	C	Possible	2	Minor	Moderate	1. The AWTP includes a side stream reverse osmosis process to maintain salt concentrations at around 500 mg/L TDS as per potable water standards. 2. Irrigation at 500 mg/L TDS is unlikely to result in vegetation impacts, except for some specific species that may have very low tolerance to salt. 3. Customer supply contracts and recycled water use agreements will advise customers not to irrigate specific plants with very low tolerance to salt.	A	Rare	2	Minor	Low
		Washdown using high salt recycled water	Corrosion of customer private assets	C	Possible	2	Minor	Moderate	1. The AWTP includes a side stream reverse osmosis process to maintain salt concentrations at around 500 mg/L TDS as per potable water standards.	A	Rare	2	Minor	Low
	SAR	Irrigation with high SAR recycled water	Potential impacts on soil structure	C	Possible	2	Minor	Moderate	1. Sandy soil profile hence the sodicity issues should not be significant. 2. Annual soil monitoring of Exchangeable Sodium Percent will be undertaken on the 3 biggest recycled water users based on customer non-potable water metre records. 3. If required customers will be required to reduce irrigation rates or undertake a gypsum application based on the recycled water use agreement. 4. If required the SAR of the recycled water supply will be reduced to <5 through by addition of calcium and magnesium and/or by reducing sodium inputs.	B	Unlikely	2	Minor	Low
	pH	Irrigation with low or high pH recycled water	Long term pH impacts on soil	D	Likely	2	Minor	Moderate	1. Maintain pH between 6.5 and 8.5 as per potable water standards. 2. Continuous online monitoring, control and alarms on pH correction system.	B	Unlikely	2	Minor	Low
		Washdown with high or low pH recycled water	Potential corrosion of private assets	D	Likely	2	Minor	Moderate		B	Unlikely	2	Minor	Low
	Chlorine	Irrigation using recycled water with high chlorine concentration	Potential impacts on vegetation and soil microorganisms	D	Likely	2	Minor	Moderate	1. Maximum free residual chlorine concentration of 2 mg/L. 2. Develop site specific chlorine dosing regimes across all seasons.	B	Unlikely	2	Minor	Low
	Trace metals, organic chemicals and other potential trace contaminants.	Trace contaminants present during irrigation	Potential impacts on soil and vegetation	C	Possible	3	Moderate	High	1. Majority residential catchment hence there is a low likelihood of significant trace contaminants being present in recycled water. 2. Customer supply contracts, recycled water use agreements and ongoing awareness and education through information provided with rates notices and via the CHB Water Utility Website. 3. Detailed annual recycled water quality monitoring for trace contaminants. 4. If contaminants are detected a source control investigation will be undertaken through analysis of trade waste and raw wastewater data. 5. If required additional treatment in the AWTP will be provided using reverse osmosis, activated carbon or ion exchange.	B	Unlikely	3	Moderate	Moderate
Stage 2 ultimate Public Open Space Irrigation System	Cross connection with potable network	Cross connection between open space irrigation network and potable water networks	Contamination of potable water supplies	D	Likely	5	Catastrophic	Very high	Cross connection control plan will be developed for the scheme and will include the following requirements for the Open Space Irrigation Network: 1. Water pressure in Open Space Irrigation Network to be maintained a minimum of 50 kPa pressure below the pressure in the potable network. 2. Unique pipe materials. Open Space Irrigation Network is to use Lilac PVC pipe. 3. Only approved, trained and supervised plumbing contractors are permitted to work on reticulation systems. 4. Monitoring of pressure and salinity differential between potable and non-potable water networks	B	Unlikely	3	Moderate	Moderate
	Unintended uses or human contact with recycled water	Unintended uses or human contact with recycled water	Potential health impacts	D	Likely	3	Moderate	High	1. Irrigation of high quality "Class A+" recycled water only 2. No above ground taps or fixtures in public open space irrigation areas. 3. Appropriate warning signage in all open space irrigation areas. 4. Lockable irrigation valves pits and controllers etc. 5. Soil moisture probes and weather station override on irrigation controllers to prevent irrigation during rainfall, high wind or elevated soil moisture. 6. Surface sprinklers with spray drift control including sprinkler nozzles that operate under low pressure with a large droplet size and low throw height.	A	Rare	3	Moderate	Low
	Spray drift during irrigation	Spray drift onto sensitive receptor	Potential ingestion of recycled water	E	Almost certain	3	Moderate	High	1. Irrigation of high quality "Class A+" recycled water only 2. Soil moisture probes and weather station override on irrigation controllers to prevent irrigation during rainfall, high wind or elevated soil moisture. 3. Surface sprinklers with spray drift control including sprinkler nozzles that operate under low pressure with a large droplet size and low throw height.	A	Rare	2	Minor	Low
	Irrigation during wet weather	Irrigation during wet weather resulting in surface runoff or deep percolation of effluent	Contamination of surface and/or groundwaters	E	Almost certain	3	Moderate	High	1. A 10 ML wet weather storage dam and a 0.85 ML recycled water storage tank provides sufficient storage during wet weather. 2. Soil moisture probes and weather station override on irrigation controllers to prevent irrigation during rainfall, high wind or elevated soil moisture.	A	Rare	2	Minor	Low

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				Likelihood		Consequence		Risk		Likelihood		Consequence		Risk
Stage 2 ultimate Public Open Space Irrigation System continued…	Irrigation rates and scheduling	Inappropriate irrigation scheduling	Increased risk of surface and ground water contamination	C	Possible	2	Minor	Moderate	1. Irrigation scheduling will use programmable irrigation controllers to control irrigation frequency, time and duration. Irrigation rates will be calibrated to ensure no ponding. 2. Irrigation rates will be seasonally adjusted in the irrigation controller to match seasonal irrigation demand.	B	Unlikely	2	Minor	Low
	Recycled water	Surface runoff during irrigation	Potential contamination of surface water	C	Possible	3	Moderate	High	1. All irrigation areas to use irrigation scheduling controls to control the time, frequency and duration of irrigation events. 2. Soil moisture probes and weather station override on irrigation controllers to prevent irrigation during rainfall or elevated soil moisture. 3. Site based storm water run off and environmental controls.	B	Unlikely	2	Minor	Low
	Nitrogen	Excessive nitrogen load resulting in leaching of nitrate from irrigation areas	Contamination of groundwater	C	Possible	3	Moderate	High	1. Irrigation of "Class A+" recycled water with total nitrogen concentration of 7 mg/L and low average irrigation rates of around 0.9 mm/day. 2. MEDLI modelling indicates all nitrogen applied in irrigation is taken up by vegetation. 3. MEDLI modelling indicates negligible nitrate concentration in deep drainage.	B	Unlikely	2	Minor	Low
	Phosphorus	Excessive phosphorous load resulting in leaching of phosphate from irrigation area	Contamination of groundwater	C	Possible	3	Moderate	High	1. Irrigation of "Class A+" recycled water with total phosphorus concentration of 0.25 mg/L and low average irrigation rates of around 0.9 mm/day. 2. MEDLI modelling indicates the majority of phosphorus applied in irrigation is taken up by vegetation. 3. MEDLI modelling indicates negligible phosphate concentration in deep drainage. 4. MEDLI modelling predicted Phosphorus adsorption into soil at a low rate of 0.3 kg/ha/year. 5. Critical P-sorption life of the soil is conservatively estimated to be >166 years based on P-sorption capacity of holocene sand.	B	Unlikely	2	Minor	Low
	Effluent Salinity	Impacts on plant growth due to salinity	Reduction in plant growth and water and nutrient uptake rates	C	Possible	2	Minor	Moderate	1. MEDLI modelling indicated no impacts on plant growth due to salinity based on a conservative effluent TDS of 1500 mg/L. 2. Landscape design processes will ensure appropriate vegetation is selected in temporary irrigation areas that can tolerate the required salt concentrations. 3. The natural sandy top soil profile and relatively high rainfall at the site will assist with flushing of salt through the soil profile to minimise potential salinity impacts on vegetation.	B	Unlikely	3	Moderate	Moderate
	Effluent SAR	Long term sodicity impacts on soil	Soil dispersion, reduction in permeability	C	Possible	2	Minor	Moderate	1. Topsoil profile is dominated by sand, hence the likelihood of sodicity impacts is low. 2. Detail geotechnical testing to be undertaken for each development stage will avoid areas with high clay content and Exchangeable Sodium Percentage (ESP). 3. Ongoing monitoring of soil cations will detect changes in soil ESP over time. 4. If required gypsum/lime application to irrigation areas will be undertaken. 5. If required the irrigation water SAR will be adjusted through addition of calcium/magnesium or reduction in sodium inputs to maintain effluent SAR<5.	B	Unlikely	2	Minor	Low
	Metals and trace contaminants	Trace contaminants is irrigation supply resulting in long term accumulation in irrigation area	Contamination of soil and groundwater	C	Possible	2	Minor	Moderate	1. Source catchment is >99% domestic wastewater hence the likelihood of trace contaminants is low. 2. Customer awareness campaigns, supply contracts, trade waste agreements and recycled water use agreements will further reduce the likelihood of events occurring. 3. Detailed monitoring of effluent quality for trace contaminant will be undertaken annually using a NATA accredited laboratory. 4. Soil monitoring in open space irrigation area will identify any build up or increase in contaminants. 5. If contaminants are detected then an investigation into the likely source will be undertaken and trade waste/source controls implemented. 6. If required additional treatment processes can be installed, e.g. BAC, ion exchange.	B	Unlikely	2	Minor	Low
	Recycled water	Pipe breakage	Potential contamination of surface or groundwater	C	Possible	2	Minor	Moderate	1. Flow and pressure monitoring in the irrigation supply system. 2. Visual inspection to identify boggy areas or erosion etc. 3. Fault and main break reporting system through customer service processes.	B	Unlikely	2	Minor	Low
	Odour	Odour released during irrigation	Odour impacts on nearby residents	B	Unlikely	2	Minor	Low	1. Irrigation of high quality "Class A+" recycled water with low BOD	A	Rare	2	Minor	Low
	Stormwater runon	Stormwater running onto irrigation areas from upgradient	Water logging of irrigation area	D	Likely	2	Minor	Moderate	1. Stormwater diversion drains to divert all upgradient stormwater runoff around effluent irrigation areas. 2. Appropriate buffers to waterways, ponds, stormwater drains and SEPP14 wetlands	A	Rare	2	Minor	Low
	Percolation to groundwater	Excessive percolation of effluent to groundwater	Contamination of groundwater	C	Possible	3	Moderate	High	1. Low long term average irrigation rate of approximately 0.9 mm/day, hence low risk of groundwater contamination. 2. Minimal presence of groundwater within 3 metres of ground surface is geotechnical investigation. 3. High quality effluent with low nutrients. 4. MEDLI modelling indicates negligible concentrations of nutrients in deep drainage for conservative sandy soil profile. 5. A minimum of 600mm sandy loam topsoil cover will be provided on irrigation areas if there is potential for seasonal high water table.	B	Unlikely	2	Minor	Low

NON-POTABLE WATER

QUALITATIVE ENVIRONMENTAL AND PUBLIC HEALTH RISK ASSESSMENT CRITERIA

From tables 2.5, 2.6 and 2.7 on Page 39 of the Australian Guidelines for Water Recycling Managing Health & Environmental Risks Phase 1 (2006)

Qualitative measures of likelihood

Level	Descriptor	Example Description from AGWR
A	Rare	May occur only in exceptional circumstances. May occur once in 100 years
B	Unlikely	Could occur within 20 years or in unusual circumstances
C	Possible	Might occur or should be expected to occur within a 5- to 10-year period
D	Likely	Will probably occur within a 1-to 5-year period
E	Almost certain	Is expected to occur with a probability of multiple occurrences within a year

Qualitative measures of consequence or impact

Level	Descriptor	Example Description from AGWR
1	Insignificant	Insignificant impact or not detectable
2	Minor	Health — Minor impact for small population Environment — Potentially harmful to local ecosystem with local impacts contained to site
3	Moderate	Health — Minor impact for large population Environment — Potentially harmful to regional ecosystem with local impacts primarily contained to on-site
4	Major	Health — Major impact for small population Environment — Potentially lethal to local ecosystem; predominantly local, but potential for off-site impacts
5	Catastrophic	Health — Major impact for large population Environment — Potentially lethal to regional ecosystem or threatened species; widespread on-site and off-site impacts

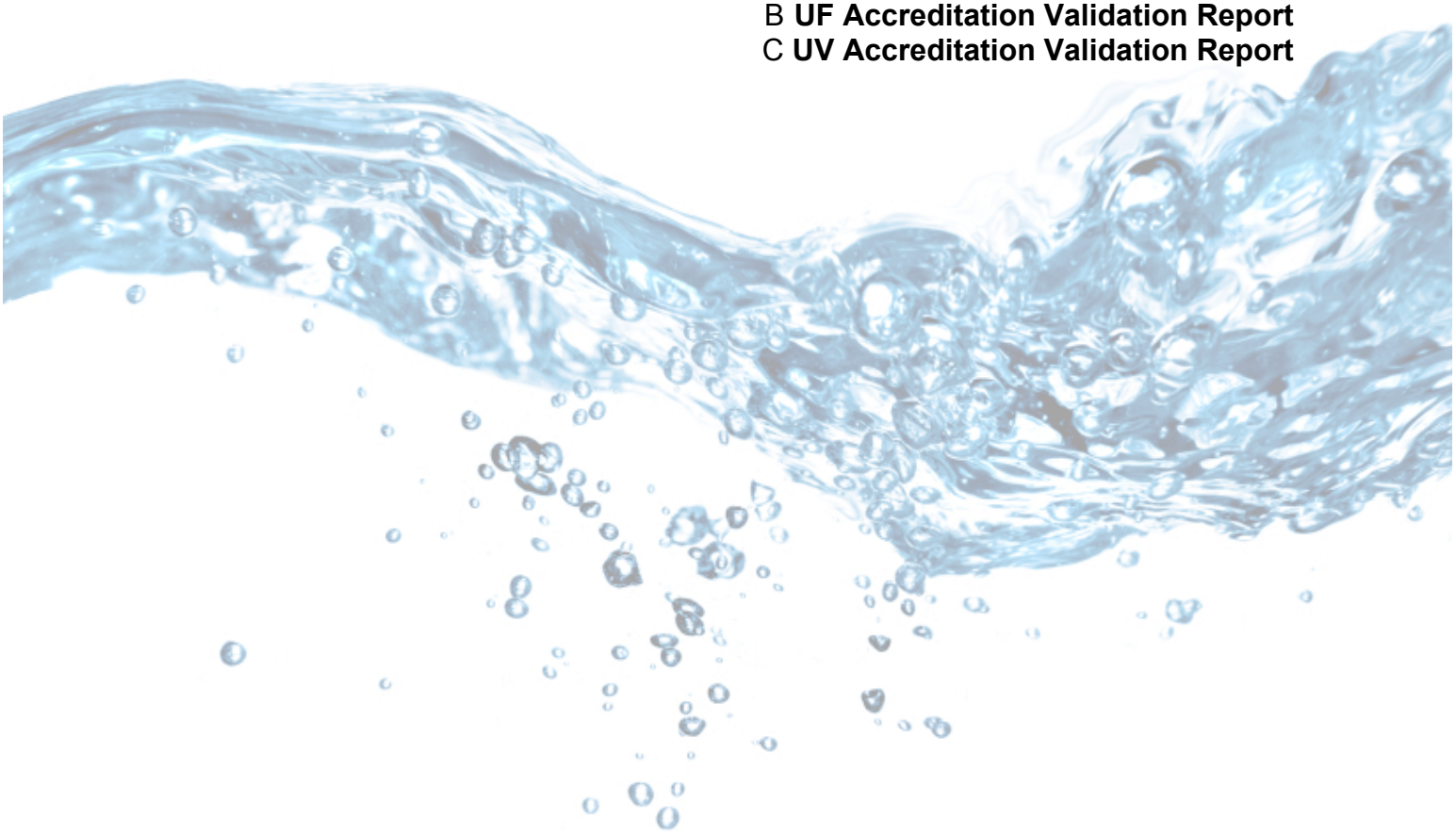
Qualitative risk analysis matrix: Level of risk

		Consequences				
Likelihood		1	2	3	4	5
		Insignificant	Minor	Moderate	Major	Catastrophic
A	Rare	Low	Low	Low	High	High
B	Unlikely	Low	Low	Moderate	High	Very high
C	Possible	Low	Moderate	High	Very high	Very high
D	Likely	Low	Moderate	High	Very high	Very high
E	Almost certain	Low	Moderate	High	Very high	Very high

Solo Water

Appendix 4.2.11 **Water Recycling**

A **Recycled Water Quality Management Plan (Fyansford Utility)**
B **UF Accreditation Validation Report**
C **UV Accreditation Validation Report**



Recycled Water Quality Management Plan

Fyansford Utility, Victoria

For the Fyansford Utility Scheme

CONTENTS

Appendices

Glossary

RWQMP**:** Recycled Water Quality Management Plan

CCP: Critical Control Point

DHS: Department of Health Services

REIP: Regional Environmental Improvement Plan

EPA: Environmental Protection Agency

HACCP: Hazard Analysis and Critical Control Point

HEMP: Health and Environment Management Plan

LRV: Log Reduction Value

TPU: Treatment Process Unit

UF: Ultrafiltration

MF: Microfiltration

UV: Ultraviolet

RO: Reverse Osmosis

1 Introduction

1.1 Purpose of the Recycled Water Quality Management Plan

This Recycled Water Quality Management Plan (RWQMP) has been prepared by Solo Water for the proposed Fyansford Utility Scheme for the Fyansford Green (Moltoni Corporation) and Riverlee (Riverlee Corporation) developments located approximately 4.0 kilometres to the North West of the Geelong Central Activities District on the Hamilton Highway as shown in Figure 1 below.

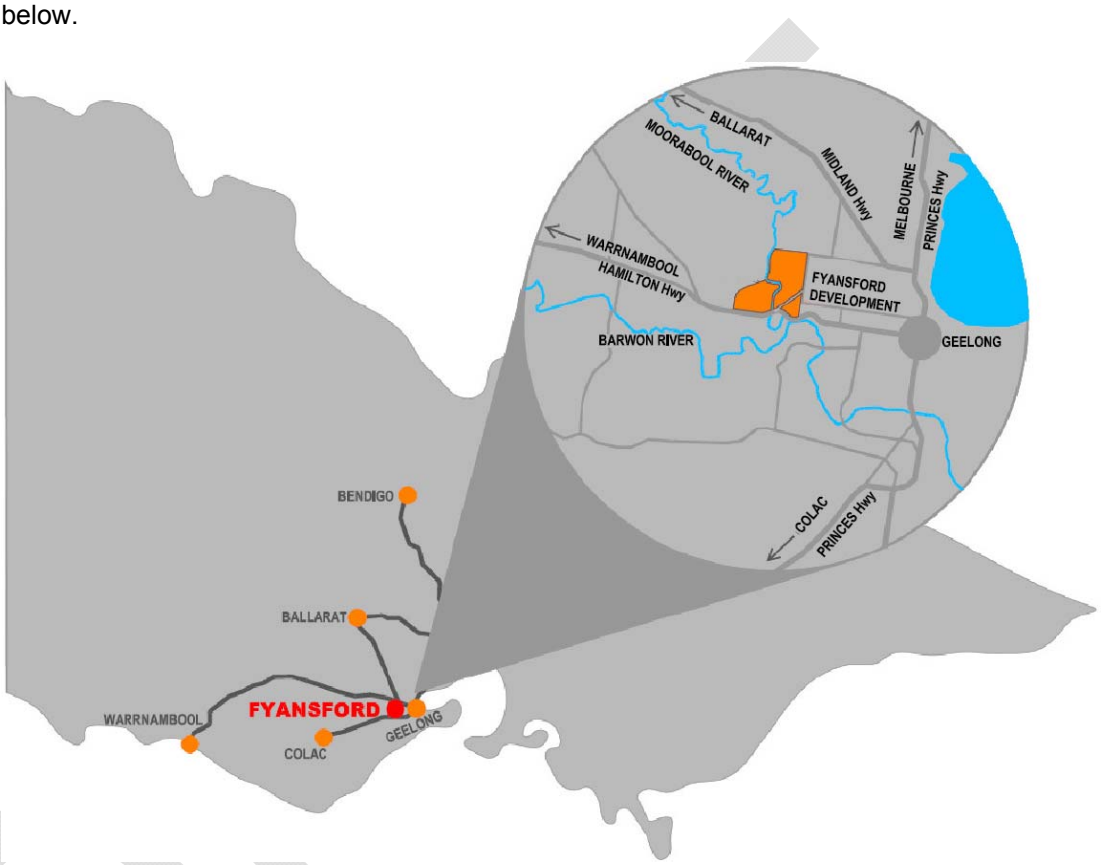


Figure 1, Fyansford Utility Locality Map

Solo Water has recently formed a new company, Fyansford Utilities Pty Ltd to provide management services for the pressure sewer collection system, the sewage treatment MBR plant, the AWT plant, ground water desalination plant, recycled water storage, recycled water pressure pumps, irrigation storages, irrigation transfer pumps, groundwater feed pumps, bore water pumps and recycled water reticulation system for all residential and commercial properties on the developments. Fyansford Utility operational structure is presented in Appendix 1.

The Fyansford Utility scheme will be responsible for supply only of recycled water to the irrigation dam on Queens Park, while the irrigation system for the golf course and playing fields in Queens Park will be managed by Greater Geelong City Council.

This plan includes detailed information on the production and supply of recycled water from the system catchment to the end of the treatment process. It addresses the responsibilities of Fyansford Utility Pty Ltd in the provision of recycled water and identifies the monitoring and controls that is necessary to produce water of an appropriate quality for the proposed end uses. Detailed information on the validation of treatment processes will also be included as part of this plan.

1.2 Management Commitment

The management of the Fyansford Utility is committed to the responsible use and management of recycled water through the implementation of preventative risk management. In doing so, Fyansford Utility management will endeavour to ensure that adequate resources are provided for recycled water programs. This includes adherence to the RWQMP, Hazard Analysis Critical Control Point (HACCP) plans and the Health and Environment Management Plans (HEMPs). Fyansford Utility management will also undertake its best efforts to ensure that the public are educated on correct recycled water use as well as the associated risks. Fyansford Utility is also committed to ongoing monitoring of these programs by undertaking audits of the recycled water management systems and through detailed investigation of human health and environmental incidents. Fyansford Utility is committed to continual improvement through the processes outlined in this plan to improve recycled water management systems where deficiencies are found.

1.3 Description of the Scheme

The proposed Fyansford Utility Pty Ltd Scheme would provide sewerage reticulation system, reticulated recycled water system for domestic reuse/irrigation purposes and wastewater treatment services for the Fyansford Green and Riverlee developments. The Fyansford Green development site is owned by the Moltoni Corporation Pty Ltd and is subject to Amendments C119 and C18, which provides for mainly residential landuse and pockets of business and mixed landuses. The Rivelee development site is owned by the Riverlee Corporation Pty Ltd and is subject to Amendment C18, which provides for residential landuse. The expected development yield of both development sites is around 1875-2145 dwellings and 4690-5360 people over the next 10 -15 years.

This RWQMP is for Stage-1 of the proposed Fyansford Green and Riverlee development sites for a proposed Wastewater Treatment Plant (WWTP) Facility to process of up to 600 kL/day of wastewater and treat it using Membrane Bioreactor (MBR) plant and Advanced Water Treatment (AWT) plant. These treatment plants will produce Class A recycled water for domestic reuse via a dual pipe reticulation system to be used for toilet flushing, washing machine, garden watering, irrigation of open space/road verges and for fire fighting. Recycled water discharges are expected to occur during the wetter months of low irrigation demand periods from the WWTP facility to the adjacent Moorabool River. These discharges will be treated by the AWT to a standard that will pose minor or negligible impacts on the environmental quality objectives and values of the Moorabool River.

Outline of the proposed works

In 2007, the Moltoni Corporation and Riverlee Corporation (after consultation and inspection of existing operating schemes) approached Solo Water to provide a sustainable solution to the provision of sewerage collection system, wastewater treatment plant, advanced treatment

facility to process treated effluent to Class A standard suitable for domestic reuse, fire fighting, irrigation purposes and a recycled water reticulation system for both developments.

Given Solo Water's prior successful delivery of similar services as a privately owned service provider at the Deep Creek Marina Resort in NSW and the Forest Resort/residential subdivision, at Creswick in Victoria, Solo Water has formed Fyansford Utility Pty Ltd to operate and maintain these services as part of the WA&L application. This will provide an integrated water cycle solution that will fully service the proposed developments with the following (Fyansford Utility scheme layout plan is presented in Appendix 2):

- A computer controlled low pressure grinder pump sewerage system to efficiently collect and transport wastewater from the development residential and commercial buildings to the WWTP site.
- WWTP that includes MBR plant to treat wastewater and AWT plant to further treat the MBR permeate to standards suitable to be used for Class A dual pipe reticulated recycled water and for discharge of excess recycled water during the wetter months to the Moorabool River without compromising the River's environmental values. The WWTP and recycled water storages will be located at the rural zoned land of the Riverlee development site north of the Geelong Ring Road.
- A desalination plant will be provided to treat local groundwater or groundwater from dewatering of the nearby Batesford quarry to ensure 100% security of the recycled water supply for domestic reuse and to supply water for irrigation of the golf course and playing fields at Queens Park, which is managed by Geelong City Council. This will be required especially in the early stages of the developments to meet the peak daily demand during the irrigation seasons. The brine wastewater stream from this process will be stored in PE lined evaporation ponds located at the WWTP site and have been sized to meet the early stages of t he developments.
- The Class A dual pipe reticulated recycled water system will be used to provide for urban non-potable water uses such as toilet flushing, washing machine, garden watering and irrigation of public open space/road verges. The excess Class A recycled water will overflow to PE lined storages to be used for irrigation of the Queens Park golf course and playing fields.

General description of the Scheme's operation

The Fyansford sustainable water management scheme has been designed to maximise the reuse of wastewater around the site to reduce the potable water demands within the development and reduce wastewater discharges to the receiving waterways. The scheme is designed to sustainably function under various operating conditions and to have 100% security in the supply of recycled water to meet its predicted non-potable water demands. The following is a brief description of the scheme's operation under various demand conditions, while schematic flow charts for the various operating modes are presented in Appendix 4.

Normal operation

- Wastewater collected from the Fyansford Green and Riverlee developments is first treated through the MBR plant for biological treatment with membrane microfiltration using 0.4 micron cartridges submerged directly into the aeration tank. MBR permeate is then treated by UF (0.03 microns) to remove viruses and protozoa.
- About 1/3 of the UF permeate is directed to RO1 to reduce salt in the recycled water to around 500 mg/L TDS. RO1 reject brine is directed towards a designated PE-lined saline evaporation pond.
- The combined permeate (partially treated by RO1) is then treated by UV to inactivate bacteria, viruses and protozoa and then chlorinated via a chlorine contact tank designed

to meet the required log removals especially for viruses. The UF, UV and chlorine contact tank act as a multiple barrier for microbes and microorganisms and are selected/designed according to the DHS requirements to demonstrate meeting the required microbial removal criteria for Class A recycled water in dual pipe schemes.

- Class A recycled water is then stored in 1.5 ML tank to supply the non-potable urban demands via a reticulated dual pipe system throughout the development site. A chlorine residual of .6 mg/L shall be maintained at all times in the recycled water tank.
- During normal operation, the rate of recycled water supply is greater than the reticulated recycled water demands. Thus, excess Class A recycled water is stored onsite in the storage dams that supply recycled water to Queens Park irrigation storage via irrigation floating pontoon pumps located in the storages. These pumps are automated by level sensors in the storages and controlled by the overall WWTP DDC control system.

Low demand operation

Low demands are generally associated with extended periods of no irrigation demands such as during winter or during extended wet weather periods.

- Production of Class A recycled water is similar to the normal operation conditions.
- When all the recycled water storage dams are full, UF permeate is entirely treated by RO1 to remove nutrients and salt to acceptable levels for discharge to the Moorabool River.

High demand operation

High demands are generally associated with extended dry periods especially in summer when irrigation demand is at its peak.

- Production of Class A recycled water is similar to the normal operation conditions.
- When the daily demand exceeds the recycled water tank capacity, recycled water from the onsite storage dams would be used to supplement the primary Class A recycled water supply from the MBR effluent stream. The recycled water stored at the dams would be treated again through the pressurised UF membrane system and into the recycled water tank, where a chlorine level of 0.6 mg/L is maintained
- When the recycled water storage dams are emptying, RO2 would be treating brackish groundwater or borewater to top-up the reticulated recycled water tank and the irrigation tank (that supplies the Queens Park irrigation storage dam) when needed. As the salinity of this treated groundwater source would be around (100-200) mg/L TDS, some of RO1 brine (which has moderate salinity compared to RO2 brine) can be mixed with this water source without compromising the quality of recycled water, which will be used for irrigation of Queens Park only. This groundwater source would provide 100% security of supply for the scheme's recycled water demand

MBR treatment plant

The MBR plant is a modified activated sludge process with a two-tier membrane bioreactor contained within a large aerobic chamber (MBR tank) designed by Solo Water. The MBR system is designed with five distinct zones contained within separate stainless steel tanks.

The MBR separates treated effluent from the mixed liquor solids utilizing a hollow fibre microfiltration membrane with a 0.4 micron pore size. The submerged membranes are typically placed directly into the MBR tank. The membranes allow the purified water to pass through the pores, while creating a complete barrier to the passage of any solid greater than 0.4 microns, which includes almost all bacteria.

Treated wastewater (or "Permeate") is drawn through the membranes using a suction lift pump leaving the suspended biomass material in the MBR tank. Biomass (mixed liquor) is removed

using a sludge pump when required to maintain the optimum mixed liquor suspended solids (MLSS) levels in the MBR plant. The illustration below gives a basic flow sheet of a typical MBR system.

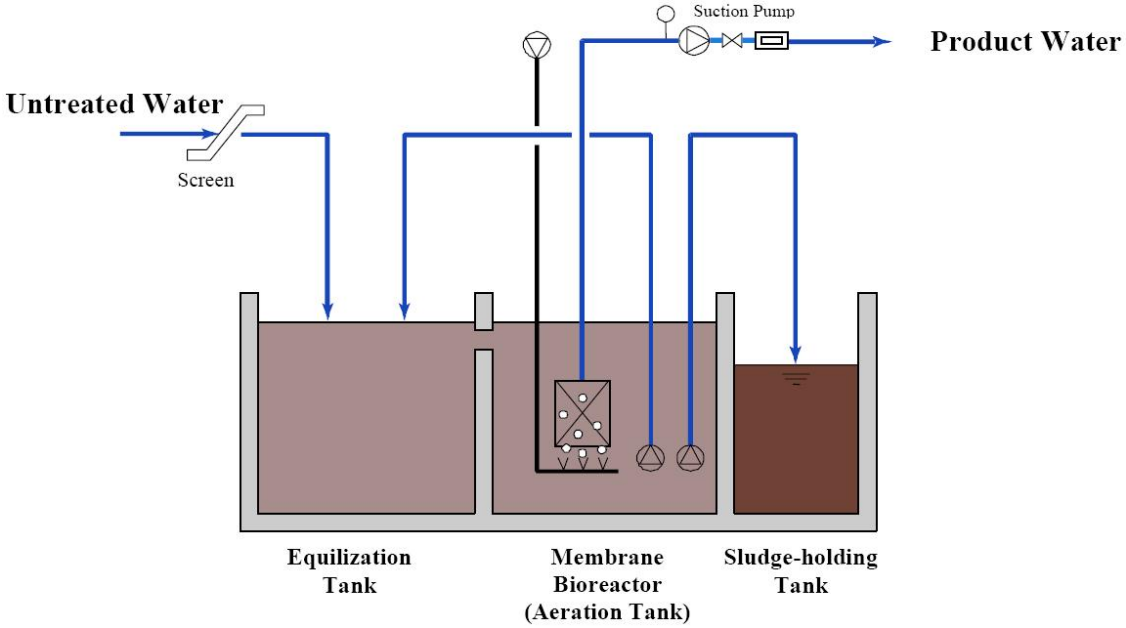


Figure 2, MBR Process

Excess sludge in the system is removed on a regular basis when the mixed liquor suspended solids concentration in the return activated sludge reaches about 13,000 mg/L (1.2% solids). Liquid sludge from the MBR will be periodically pumped from the system to a collection tanker and disposed of to an EPA licensed facility by an approved tank waste contractor.

Figure 3, Existing MBR treatment works at Forest Resort (Creswick VIC)

Advanced Water Treatment plant

The objective of the AWT plant is to further treat the MBR permeate to produce recycled water of the following qualities:

- Class A recycled water, which would be used in the dual pipe reticulation system for unrestricted non-potable water uses across the development site such as toilet flushing, washing machine, garden watering, fire fighting, road verges and public open space

irrigation. The quality of Class A recycled water should comply with the DHS microbial criteria for dual pipe water recycling schemes as follows:

Bacteria	<10 E. Coli/100 mL
Viruses	7-log reduction from raw sewage to recycled water
Protozoa	6-log reduction from raw sewage to recycled water

For this purpose, the MBR permeate will be further treated by UF, UV and chlorination specifically designed to demonstrate compliance with DHS requirements using DHS endorsed treatment equipment and operational monitoring. Additionally, RO1 will be utilised to treat 30% of the UF permeate during normal operation conditions to reduce salt in the recycled water to around 500 mg/L TDS. The expected water quality of the recycled water during operation would be as shown below:

BOD	<5mg/L
SS	<5mg/L
pH	6.5-8.5
Turbidity	<1 NTU
TN	<7mg/L
TP	<0.25mg/L
TDS	<500mg/L

- Recycled water discharge to the Moorabool River during extended periods of no irrigation demands such as during winter or during extended wet weather periods and when all the recycled water storage dams are full. UF permeate will be entirely treated by RO1 to remove nutrients and salt to acceptable levels for discharge to the Moorabool River. The following water quality standard is expected for the recycled water discharges to Moorabool River following 100% treatment by RO1:

BOD	<5mg/L
SS	<5mg/L
pH	6.5-8.3
Turbidity	<1 NTU
TN	<3mg/L
TP	<0.1mg/L
TDS	<100mg/L

Ultrafiltration (UF) membrane unit

The UF membrane unit will be installed in series after the MBR unit. Ultrafiltration is a pressure driven process in which the fine-pore membrane acts as a selective barrier to restrict the passage of pollutants in the feed water. The UF unit is manufactured by Norit X-Flow (model UFC M5, 0.8mm) with an absolute pore size of 0.03 µm. The primary function of the UF unit is to filter the MBR permeate to remove microorganisms and microbes such as viruses and protozoa. The UF membrane unit is sized to treat a maximum of 1.1 ML/day, which can cater for the average daily operational flow from the MBR plus treating previously treated Class A recycled water stored in the recycled water dams.

Figure 4, Existing UF membrane unit at Deep Creek Resort (Moama NSW)

Reverse Osmosis unit (RO1)

Reverse Osmosis is a process for the removal of dissolved ions from the permeate in which pressure is used to force the water through a semi-permeable membrane, which will pass the water but rejects most of the dissolved solids including salt and nitrates. RO1 treatment unit has a design capacity of 0.4 ML/day with about 85% recovery and will be installed within the WWTP building. RO1 unit is skid-mounted low energy brackish water RO membranes manufactured in Thin Film Polyamide by Filmtech

RO1 is designed to treat about 1/3 of the UF permeate during normal operation to reduce salinity to around 500 TDS. However, since the recycled water quality standard for discharge to the Moorabool River is more stringent, especially from a nutrient perspective to ensure that recycled water discharges don't compromise the River's environmental values, RO1 will have to fully treat the UF permeate during such circumstances.

Ultraviolet (UV) disinfection unit

A UV disinfection unit manufactured by Orica (model AFP840) will be used to further treat the UF permeate (partially through RO1) to inactivate bacteria, viruses and protozoa. The efficiency of this unit in virus and protozoa log removal is assessed according to the DHS requirements and is discussed later in this report.

Chlorination system

Chlorination is undertaken within the WWTP and the recycled water reticulation system as follows:

- Pre-chlorination of the MBR permeate before feed to UF membrane system.
- Chlorination using a contact tank designed with baffles and appropriate retention time to achieve the required log-removal by the *GEM Dual pipe Water Recycling Schemes-Health and Environmental Risk Management* and endorsed by DHS.
- Chlorination at the dual pipe recycled water tank to ensure continuous residual chlorine of 0.6 mg/L at all times.

Groundwater supply and desalination plant

A Reverse Osmosis membrane desalination plant (RO2) is proposed to treat groundwater from either dewatering of the Batesford quarry or the local bore, to reduce salinity levels in

groundwater to about 200 mg/L so that it can be used to top-up the dual pipe recycled water tank and the irrigation dam at Queens Park.

Control system

The MBR equipment is controlled by the Main Plant Control System provided by Sirex. Readings from instruments are electronically recorded and controls for many instruments can be electronically and remotely monitored and triggered using the Plant Control System. The Plant Control System can operate under Manual and Automatic control modes. The basic system logic and operating requirements are to be detailed in the Functional Description included in the WWTP Operation and Maintenance Manual, which is to be prepared and finalised during the commissioning phase.

A computer controlled blower aerates the sewage and a permeate pump draws the product water through the membranes and discharges it into the permeate pipe for subsequent UF, RO, UV and chlorine dosing. The level in the anaerobic tank controls the speed of permeate pump to maintain the consistency of the treatment process. As the concentration of solids increases in the permeate line to a set point, the operator will pump the sludge-liquor back to the inlet tank or directly to a tanker for offsite disposal. The MBR tank can be decanted back to the aeration tank as required.

After MBR effluent has undergone UF treatment a proportion of it is automatically diverted to the RO1 unit to be collected again with the remainder of the UF permeate in the UV feed tank.

Wastewater Treatment Plant Building

The equipments for the MBR and AWT plants will be enclosed in a building, with approximate dimensions of 60m by 15m located at the rural zoned land on the Riverlee development site north of the Geelong Ring Road. Additional space of 20m x 15m will also be provided for future upgrade of the plant to cater for the subsequent stages of the project. The dual pipe pumps and irrigation pumps will also be contained within the plant building. The layout of the WWTP building is shown in Appendix 3. Photos of an existing MBR installation already operating at Forest Resort in Creswick Victoria are shown below.

Figure 5, existing treatment plant building

Dual pipe reticulation and storage

Recycled water storages will be utilised to improve the security of supply of the Class A dual pipe reticulation system. Class A treated recycled water will be first stored in a 1.5 ML tank that directly supplies the dual pipe reticulation system, which distributes recycled water for urban non-potable water demands such as toilet flushing, washing machine, garden irrigation, wash

down, fire fighting and irrigation of road verges and public open space. The recycled water piping system will use purple coloured PVC piping to distinguish it from the potable supply to the development in accordance with the plumbing code and AS3500. It will also be clearly labelled as non-potable water at the point of end use.

Excess Class A recycled water is then stored in 25 ML storage dams on the site of the WWTP north of the Geelong Ring Road. These storages will supplement the dual pipe recycled water tank during times of peak demand by Class A treated recycled water after further treatment by UF and chlorination addition at the recycled water storage tank. These storage dams will also pumps recycled water to the irrigation storage dam in Queens Park. These storage dams will be PE lined to reduce water loss and seepage to the underground water aquifer.

Recycled water irrigation only scheme

Part of the Fyansford Utility scheme is to provide recycled water to Queens Park, which is owned and managed by GGCC. An in principle agreement has been reached to this effect between Fyansford Utility and GGCC. Initially, Fyansford Utility would supply the estimated 70 ML/year irrigation demand from treated groundwater. This will be replaced by the following sources as the Fyansford Green and Riverlee sites are progressively developed:

- Class A recycled water
- During high irrigation demand periods and when the recycled water storage dams are emptying, a shandy of desalinated groundwater and RO1 brine would be used. The salinity of the shandy should not exceed 500 mg/L TDS.

Fyansford Utility will only supply recycled water to the storage dam in Queens Park to be used for restricted irrigation purposes under a HEMP, specifically prepared for this purpose. GGCC will be responsible for operation of the irrigation system to the golf course and playing fields within Queens Park under the conditions of the HEMP.

This irrigation storage dam will also be PE lined to reduce water loss and seepage to the underground water aquifer.

Saline evaporation ponds

A total of 1.6 ha active surface area PE lined evaporation ponds will be provided with a depth of 2.5m to sustainably manage the brine wastewater streams from both RO1 and RO2.

Discharge to waterways outlet

During extended wet weather periods when all the recycled water storages are full, RO1 treated excess recycled water will be discharged from the WWTP to the adjacent stormwater collection system, currently managing stormwater runoff from the adjacent Geelong Ring Road and then to Moorabool River via stormwater drainage within the Riverlee site

2 Roles and Responsibilities

The roles and responsibilities of the supplier, scheme manager and users are summarised in the sections below.

2.1 Supplier and Scheme Manager

As the supplier and scheme manager, Fyansford Utility will be responsible for:

- Developing, implementing and reviewing the RWQMP
- Obtaining DHS endorsement for Class A RWQMP
- Supplying recycled water to quality standards set out in the RWQMP and HEMP to end users
- Ensuring that the Environmental Improvement Plan (EIP) and Health and Environment Management Plan (HEMP) are EPA endorsed
- Annual Review of HEMPs
- Annual review of Customer Site Management Plans
- Annual review of RWQMP and HACCP
- Annual report to the EPA, including all monitoring results as required by the RWQMP, HACCP and HEMPs
- Maintenance and update of operational management programs
- Monitoring of water quality throughout the system
- Provision of alternative supply when necessary
- Maintain record of recycled water users
- Provide EPA with annual list of recycled water users
- Communication with customers during an incident
- Notification of EPA of an incident or exception within 14 days
- Notification of EPA of an emergency immediately
- Assessment and review of customer compliance
- Undertaking of internal audits and arrangement of statutory, third party, external audit, in compliance with AS/NZS 19011:2003 *Guidelines for Quality and/or Environmental Management Systems Auditing*
- Action against users who do not comply with HEMP and site management plan.

2.2 Users

Users of recycled water from this scheme will be responsible for compliance with customer site management plan and HEMP.

3 Water Quality Objectives

This section is intended to describe how water quality objectives are met in relation to human health protection. Requirements and guidelines for level of treatment and water quality objectives for human health are taken from the following references:

- Guidelines for Environmental Management – Dual Pipe Water Recycling
- Australian Guidelines for Water Recycling

3.1 Microbial

The risks posed by pathogens via exposure through the expected uses of recycled water in dual pipe schemes have been analysed and assessed using a Quantitative Microbial Risk Assessment by the EPA to determine the microbial criteria that will ensure adequate public health safety. Details of this Quantitative Microbial Risk Assessment are presented in the EPA's document *Health Risk management in urban Recycling Schemes: Technical Background Paper*. This microbial criteria, which are expressed as water quality targets in *GEM Dual pipe Water Recycling Schemes- Health and Environmental Risk Management (2005)*, are presented in Table 1 below.

Table 1: Class A recycled water quality targets as outlined in *GEM Dual Pipe Water Recycling Schemes - Health and Environmental Risk Manaagement (2005)*

Pathogen Group	**QMRA Criterion**
Bacteria[1]	<10 *E.Coli*/100ml
Viruses[2]	7-log reduction[3] from raw sewage to recycled water
Protozoa[2]	6-log reduction[4] from raw sewage to recycled water

Notes:
[1] Median – to be demonstrated during treatment plan validation
[2] As a default, the most resistant (or worst case virus) virus or protozoan should be used at each treatment step for calculating log reductions.
[3] Median removal, with a lower (critical) limit of 6-log reduction
[4] Median, with a lower (critical) limit of 5-log reduction

Microbial criteria are expressed as water quality targets for bacteria where target concentrations are measureable, and as treatment performance targets for viruses and protozoa. This is because direct measurement of target concentrations is impractical due to limitations in analytical techniques. Water quality criteria have not derived for helminths (parasitic worms) as helminth infections are not considered endemic in most parts of Australia and it is considered that treatment processes providing a significant proportion of protozoan removal by sedimentation and/or filtration would effectively remove helminth eggs. These microbial criteria are applied at the end of the treatment process prior to recycled water entering the distribution system or being introduced into storage.

Acceptable uses of Class A recycled water of the quality specified in Table 1 above according to *GEM Dual pipe Water Recycling Schemes- Health and Environmental Risk Management (2005)*, which are also adopted for the Fyansford dual pipe recycled water scheme include:

- Irrigation of public open spaces such as parks and sport fields, where public access is unrestricted and any irrigation method is used.
- Domestic garden watering including vegetable gardens.
- Toilet flushing and washing machine use.

- General outdoor uses such as car washing, dust suppression, construction and wash down
- Filling water features and ponds that are not used for swimming.
- Use in cooling towers.
- Fire fighting and fire protection systems including hydrants and sprinkler systems.

The expected treatment plant performance of the proposed water treatment process is outlined in Table 2 below. This is expressed in log reduction values (LRV) attributed to specific treatment process units (TPU). More information will be provided in Chapter 5 of this report to validate this expected treatment plant performance.

Table 2: expected treatment plant performance the Fyansford water utility scheme

Pathogen	Class A Target Log Reduction	Fyansford Proposed Water Treatment Process					
		MBR	UV	UF	RO	Cl	Total
Adenovirus/MS2	7 - log	-	negligible	3.5		4	7.5
Cryptosporidium:	6 - log	-	2.5	4		0.2	6.7

3.2 Chemical

Given that recycled water for the Fyansford development will originate from domestic sources, the health risk posed by chemical contaminants is typically less that that posed by pathogens. Metals and organic compounds tend to settle into the sludge stream and are then subject to management through the treatment process. For this reason, no guidance is provided for chemical contaminants in the *GEM: Use of Reclaimed Water (2003).* Therefore, the presence of chemicals in recycled water at levels that could potentially pose a health risk is not anticipated for this scheme. According to the EPA guidelines, chemicals entering the sewerage system are managed through trade waste control, substantially diluted with other wastewater, and generally removed or degraded by treatment processes. Due to this, the EPA has not established specific water quality objectives for chemicals.

4 System Assessment

This section will provide an overview of the recycled water system and identify potential sources of risk that will require control. It is intended that monitoring and management for achieving and maintaining the required microbial criteria will occur through the application of a Hazard Analysis and Critical Control Point (HACCP) framework. The aim of the system assessment is to provide a detailed understanding of:

- The entire recycled water supply system, from source to end use or receiving environment
- The hazards, sources and events (including treatment failure) that can compromise recycled water quality
- The preventative measures needed to effectively control hazards and prevent adverse impacts on humans and the environment.

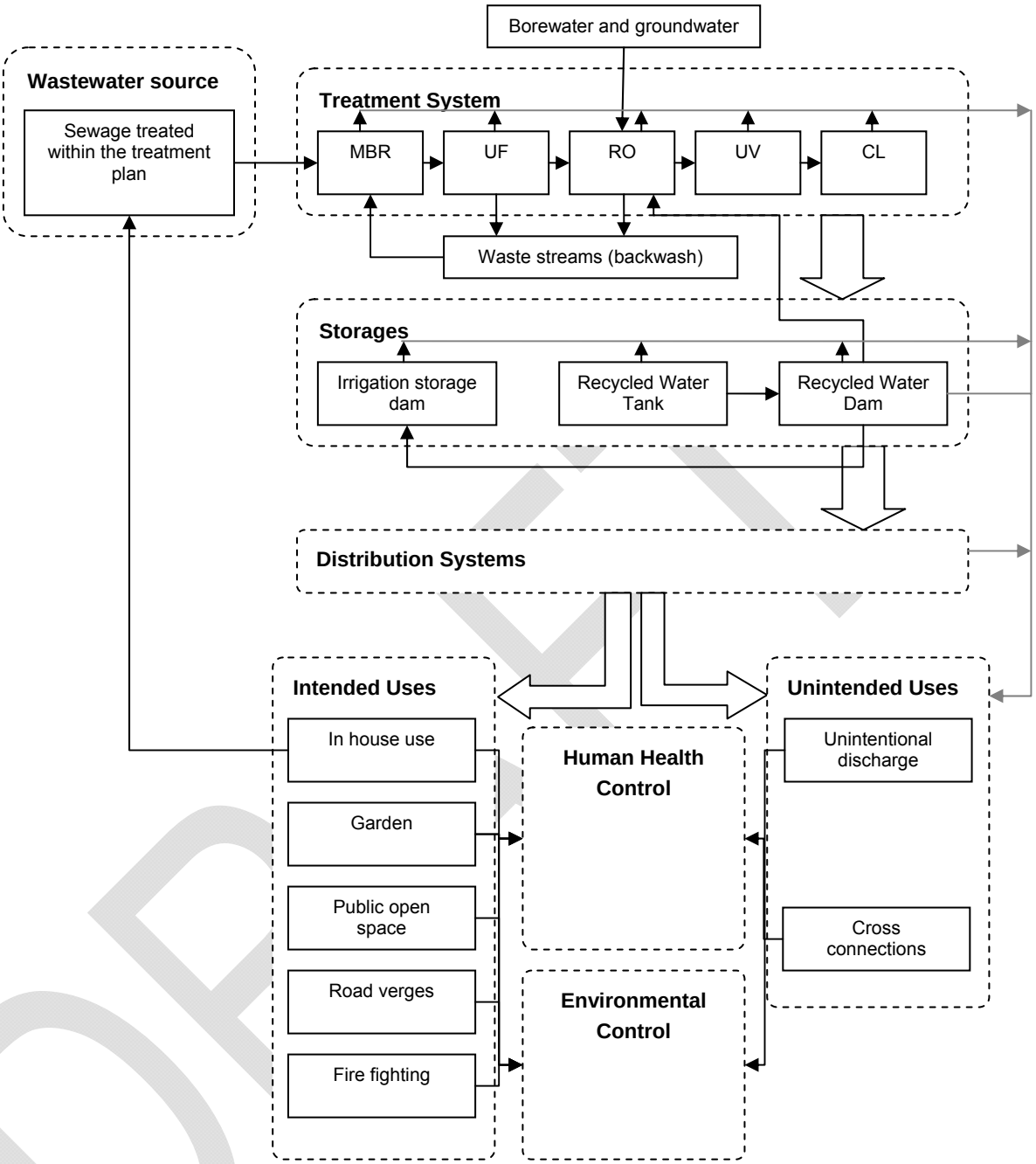
4.1 Intended uses and source of recycled water

The recycled water for this system is intended to be primarily sourced from domestic sewage from the Fyansford Green and Riverlee developments. The intended end uses of recycled water for this system are:

- Irrigation of Queens Park
- Domestic garden watering including vegetable gardens.
- Toilet flushing and washing machine use.
- General outdoor uses such as car washing, dust suppression, construction and wash down
- Filling water features and ponds that are not used for swimming.
- Use in cooling towers.
- Fire fighting and fire protection systems including hydrants and sprinkler systems.

4.2 Recycled water system analysis

Below is a generalised flow diagram describing the intended recycled water system from source to end use (or receiving environment). This diagram helps to outline all the steps and processes involved within the system and determine whether they are under the control of Fyansford Utility. It can also highlight any explicit characteristics or risks associated with the system.



4.3 Hazard Identification and Determination of Critical Control Points

A number of hazards have been identified for recycled water collection, treatment, storage and end use. A hazard control table (Appendix 5) has been developed to identify actions and controls which will aid in mitigating risk and reduce the likelihood of their occurrence during production, supply and use of recycled water. This table documents the following information as part of the hazard analysis procedure:

- Identification of hazards and associated hazardous events at each step in the water treatment and use process.
- Identification of the likelihood and consequence of each of these hazards

- Determination of the risk and significance of each hazardous event (i.e. likelihood multiplied by consequence)
- Identification of control measures for each hazardous event. This can include system input management, physical barriers, monitoring standard operating procedures and education.
- Personal responsible for carrying out control measures.

Major hazards identified through this procedure include:

- Chemical contaminants in domestic sewage
- Increased BOD and ammonia due to mechanical failure of blowers
- Spill of toxic chemicals on site
- High levels of human pathogens in recycled water
- High levels of organic chemicals in recycled water
- Chemical contaminants in the membrane filtration scheme
- Vector borne diseases in recycled water storage
- Algal blooms in recycled water storage
- High levels of nutrients in recycled water
- High levels of residual chlorine in recycled water

These hazards can occur at many processes throughout the water reuse system including:

- The collection of sewerage and production of recycled water
- The storage of recycled water
- The domestic use of recycled water from a dual reticulation system
- Irrigation with recycled water

The risk analysis matrix framework from the *Australian Drinking Water Guidelines* (NHMRC 2004) was used in assessing the risk of each hazard. Once the risk is assessed for the identified hazards, preventative measured will be developed to mitigate these risks to an acceptable level. Examples of preventative measures include:

- Protection of water source by protecting stormwater from animal and human waste, and controlling the type of water discharged into greywater systems.
- Water treatment to reduce hazards
- Water storage methods to reduce hazards
- Protection and maintenance of distribution systems and storages, including
    - Buffer zones
    - Light minimisation to restrict algal growth
    - Maintaining drainage and sites
    - Backflow prevention and cross connection control
- Restrictions on distribution systems and application site, such examples include:
    - Adoption of recycled water plumbing codes of practice
    - Control of access, application methods, rates and times etc
    - Development of management plans
    - Signage and education.

Critical Control Points (CCPs) are defined as a point, step or procedure at which control can be applied and is essential to prevent or eliminate a hazard or reduce it to an acceptable level. Identification of CCP's is particularly important for assuring water quality. Potential CCPs for the Fyansford plant have been preliminarily developed based on initial knowledge of potential

hazards and associated risks, and preventative measures identified through the HACCP process. These are outlined in Table 3 below along with their associated criteria:

Table 3: Potential CCPs at the Fyansford water utility scheme

Process Step	Hazard	Do preventative measures exist to reduce the hazard/risk to an acceptable level?	Is the preventative measure specifically designed to substantially reduce the risk presented by the hazard?	Can operation of the preventative measure be monitored and corrective actions are applied in a timely fashion?	Would failure of the preventative measure lead to immediate corrective action or possible cessation of supply?	Is this a CCP?
Interface at inlet	Microbiological pathogens	Yes	No	No	No	No
Interface at inlet	Chemical contaminants	Yes	Yes	Yes	Yes	Yes
Primary sedimentation	Suspended soils, BOD, *E.coli* and other biological pathogens.	Yes	Yes	Yes	Yes	Yes
Aeration tanks	BOD, ammonia	Yes	Yes	Yes	Yes	Yes
Membrane bioreactor	BOD, biological pathogens	Yes	Yes	Yes	Yes	Yes
Chlorination	BOD, biological pathogens, chlorine residual	Yes	Yes	Yes	Yes	Yes
UV disinfection	BOD, biological pathogens.	Yes	Yes	Yes	Yes	Yes
Ultra filtration	BOD, biological pathogens.	Yes	Yes	Yes	Yes	Yes
Reverse Osmosis	BOD, biological pathogens.	Yes	Yes	Yes	Yes	Yes
Recycled water reticulation (Domestic)	BOD, biological pathogens, chlorine residual	Yes	Yes	Yes	Yes	Yes
Recycled water reticulation (Public open space irrigation)	BOD, biological pathogens	Yes	No	No	No	No
Storage lagoons	Algal bloom, contamination from animals.	Yes	Yes	Yes	Yes	Yes
Retention tanks	Algal bloom, contamination from animals.	Yes	No	No	No	No

Following identification, the requirements for each of the CCP's are as follows:

- Operational parameters that can be measured, and for which critical limits can be set to define effectiveness
- Operational parameters that can be monitored sufficiently frequently to reveal any failures in a timely manner

- Procedures for corrective action that implement in response to deviation from critical limits.

4.4 Critical limits and alert criteria

Critical limits have been defined and validated as part of the preventative measures outlined for each CCP identified. A critical limit represents a quantitative or qualitative tolerance level which distinguishes acceptable from unacceptable performance for each CCP. Exceedance of critical limits during a process at each CCP represents loss of control of a process and indicates that there may be an unacceptable health or environmental risk. Corrective actions have been developed in the event of a deviation from critical limits at any CCP. Alert criteria have been established to provide early warning that a critical limit is being approached. The alert criteria are more stringent that critical limits and serve to institute corrective actions before an unacceptable health or environmental risk occurs. Preliminary critical limits and alert criteria developed for the Fyansford utility are outlined in Table 4 below.

Table 4: Potential critical limits and alert criteria for the CCPs

Potential Critical Control Point	Hazard(s)	Potential Critical Limit	Potential Alert Limit
Interface at inlet	Chemical contaminants		
Primary sedimentation	Suspended soils, BOD, *E.coli* and other biological pathogens	Filtered water turbidity ≤ 2 NTU 95% of the time. Maximum turbidity of 5 NTU	
Aeration tanks	BOD, ammonia		
Membrane bioreactor	BOD, biological pathogens		
Chlorination	BOD, biological pathogens, chlorine residual		
UV disinfection	BOD, biological pathogens.	UVT 80% Peak flow rate 8 L/s Max pressure 450 kPa	
Ultra filtration	BOD, biological pathogens.	Flux 76 l/m^2/hr Transmembrane pressure (TMP) 0.9 bar UCL for monitored air flow during DIT 236 l/hr Turbidity UCL 0.15 NTU Particle counting and particle monitoring, 95% confidence interval of the previous month's data	Alarm CL for monitored air flow during DIT 97 l/hr Turbidity alarm CL 0.1 NTU
Reverse Osmosis	BOD, biological pathogens.		
Recycled water reticulation (Domestic)	BOD, biological pathogens, chlorine residual	Zero cross connections and backflow prevention provided at property boundaries	
Storage lagoons	Algal bloom, contamination from animals.		

5 Validation of Treatment Process

Validation is a critical component of the treatment process management to ensure that the targeted water quality objectives are achieved. DHS validation and endorsement is required to ensure that the targeted water quality objectives outlined by the EPA are achieved for Class A recycled water for dual pipe use. DHS requires that individual processes within the treatment train are validated through the following methods:

- Considering data which already exists
- Specific on-site testing of full-scale or pilot systems
- On-site tracer studies

For the purposes of this draft RWQMP, existing data was considered to meet validation requirements and receive DHS endorsement. Specific on-site testing of the facility will be undertaken upon completion of construction to verify the validation requirements outlined at this stage. It is essential to demonstrate sufficient log removal achievements from each individual process within the treatment train. Demonstration of log removal from each process is explained in detail below.

5.1 Membrane bio-reactor (MBR) process

The MBR plant is an improved activated sludge process by introducing a hollow fibre membrane filter into the final stage of the aeration treatment, which separates treated effluent from the mixed liquor suspended solids producing high quality permeate. Microfiltration (MF) membrane manufactured by Mitsubishi Rayon will be used, which is sterapore hollow fibre 0.4 micron polyethylene membrane. Each membrane module, or cassettes, consists of 70 horizontal curtains of fibres. The cassettes are placed directly into the aeration basin and a vacuum pump is used to pull clean water through the membrane while leaving the biomass in the MBR tank basins.

While previous research indicated that MBR process removes pathogens including bacteria, protozoa and sometimes viruses. However, According to DHS requirements, the capability of a secondary treatment process to reduce pathogens needs to be characterised over an extended period of time to consider seasonal variation, catchment inputs and process upset. Such testing typically occurs over a 12 month period. As such, the MBR process will not be considered as part of the validated treatment train to demonstrate meeting the microbial water quality criteria as set by the *Dual Pipe Water Recycling Schemes- Health and Environmental Risk Management (2005)*.

5.2 Ultra-filtration membrane (UF)

DHS requires that validation reports for membrane filtration systems in support of log reduction claims be according to the guidance provided in the *USEPA Membrane Filtration Guidance Manual (2005)*. The X-Flow UF membrane (Model UFC M5, 0.8mm) manufactured by Norit is selected to be used for the Fyansford Utility AWT plant. This UF membrane model has been tested according to the *USEPA Membrane Filtration Guidance Manual (2005)* by Kiwa N.V. The full testing report is provided in Appendix 6, while summary of the testing results are outlined below.

5.2.1 Challenge testing

Test system

The membrane elements that were tested were of the type S-225-FSFC PVC containing UFC M5 0.8mm membranes. Three membranes were installed in a pressure vessel. The vessel was

fed by a feed pump with drinking water at a flow of 5.5, 10.5 or 14 m^3/h. The micro-organisms were dosed into the feed water to obtain a feed concentration of approx. 10^{6-7}/l. A combination of intact and broken fibre membrane elements were tested. After the experiments the membrane elements were re-tested in a bubble test to verify the number of broken fibres after the experiment was identical to the number of broken fibres prior to the experiment.

Virus

- Challenge experiments with MS2 bacteriophages have been used as indicator for the removal of human pathogenic viruses, such as Hepatitis A and Norwalk-like caliciviruses.
- The results of the challenge test with intact membrane elements shown that the log removal achieved by the membrane is in the range of 4.0 - 5.6 logs showing a trend of decreasing removal with time.
- The results of the challenge test with broken fibre membrane elements shown that the log removal achieved by the 0.5 broken fibre per module is in the range of 3.9-5.0 logs, by the 1 broken fibre per module is in the range of 4.0-4.9 logs and by the 2 broken fibres per module is in the range of 3.9-5.1 logs.

Giardia and cryptosporidium

- Challenge experiments with *Bacillus subtilis* (approx 1 µm) spores are regarded as an indicator for the removal of persistent organisms, such as Cryptosporidium.
- The results of the challenge test with intact membrane elements shown that the log removal achieved by the membrane is greater than 6.9 logs.
- The results of the challenge test with broken fibre membrane elements shown that the log removal achieved by the 0.5 broken fibre per module is in the range of 3.7-4.0 logs, by the 1 broken fibre per module is in the range of 3.8-4.4 logs and by the 2 broken fibres per module is in the range of 4.6-5.9 logs.

5.2.2 Direct Integrity testing

Virus

A key factor limiting the virus removal credit awarded to membrane systems is the lack of a direct integrity test able to quantify virus removal through small integrity failures. The pressure required to demonstrate a membrane breach that is the size of a virus particle is significantly higher than what any current, commercially available membrane can withstand without rupturing. To overcome this issue, DHS recommended that virus challenge test be undertaken using broken fibre to simulate worst-case scenario of having virus sized breaches of the membrane fibre that cannot be detected using direct or indirect integrity testing. The virus log removal determined from the earlier challenge test for broken fibre membrane elements will be adopted in this regard, which shows that the lowest virus log removal value was 3.9.

Giardia and cryptosporidium

- Log removal value (LRV) for X-Flow UF membrane system was established using a number of laboratory tests and data from full scale plants using the Diffusive Airflow Test as described in the Technical Bulletin *LT2ESWTR-LRV Calculations through direct integrity testing* prepared by Norit (2006), which is based on the *USEPA Membrane Filtration Guidance Manual (2005)* and is provided in Appendix 6 of this report.
- NORIT has tested single fibres at different lengths. Each time five fibres have been tested simultaneously in order to increase the accuracy of the laboratory testing. The testing is aimed to determine the Air to Liquid Conversion Factor (ALCR) as described in the *USEPA Membrane Filtration Guidance Manual (2005)*.The results indicated that air test pressure to be applied can vary between 0.845 bar to 2.5 bar. Norit recommends performing airflow testing at 1.0 bar. The ALCR has been calculated for 1 bar test air

pressure and a fibre cut at the potting. The results are expressed in the following regression equation:

$ALCR = 38.914 \times TMP^{-0.7224}$

Where TMP is the trans membrane pressure during filtration.

- LRV can be calculated according to the following equation (equation 11 of the Norit Technical Bulletin *LT2ESWTR-LRV Calculations through direct integrity testing 2006*):

$$LRV = \log \frac{Q_p \times 38.914 \times TMP^{-0.7224}}{Q_{air\text{-}monitored} - Q_{air\text{-}diffusive}}$$

Where:

LVR	log removal value for the Direct Integrity Test
Q_p	permeate flow during filtration (m^3/hr)
TMP	transmembrane pressure during filtration (bar)
$Q_{air\text{-}monitored}$	Displaced water flow during airflow testing (m^3/hr)
$Q_{air\text{-}diffusive}$	Diffusive air flow at 1 bar test pressure (m^3/hr)

Control limits

The *Membrane Filtration Guidance Manual (2005)* requires that control limits must be established for a direct integrity test, representing a threshold response which, if exceeded, indicates a potential integrity problem and triggers subsequent corrective action. The following equations were provided by the Norit Technical Bulletin *LT2ESWTR-LRV Calculations through direct integrity testing 2006*:

- The Upper Control Limit can be calculated according to the following equation:

$$UCL_{monitored} = \frac{Q_p \times 38.914 \times TMP^{-0.7224}}{10^4} + Q_{air\text{-}diffusive}$$ *(Equation 14: upper control limit)*

- The alarm level control limit can be calculated according to the following equation assuming achieving 4.5-log cryptosporidium removal as a threshold for the alarm, so corrective action can be taken without plant shutdown:

$$CL_{monitored} = \frac{Q_p \times 38.914 \times TMP^{-0.7224}}{10^{4.5}} + Q_{air\text{-}diffusive}$$ *(Equation 16: alert control limit)*

Where:

$UCL_{monitored}$	monitored upper control limit (
Q_p	permeate flow during filtration (m^3/hr)
TMP	transmembrane pressure during filtration (bar)
$Q_{air\text{-}diffusive}$	Diffusive air flow at 1 bar test pressure (m^3/hr)

LRV & Control limits for the proposed system

- The following design information is used for the Fyansford UF membrane system (more detailed information is presented in Appendix 6):
  - One unit with four housings. Each housing would have 4 membrane elements (i.e total number of membrane elements is 16).
  - Gross filtration flux is 76 l/m^2/hr and the total membrane area is 640 m^2. this makes the permeate flow during filtration (Q_p) = 48.6 m^3/hr
  - The transmembrane pressure during filtration (TMP) for the Norit X-Flow UF membrane system is (0.3-0.9). TMP of 0.9 will be used to calculate the Upper

Control Limit (UCL), alarm Control Limit (CL) and the Log Removal Value (LRV) as this would produce more conservative values.

- The diffusive air flow through an intact fibre depends on the actual set up of the membrane units and the airflow testing equipment, which is therefore site specific. Norit have access to several full scale plants that utilize airflow testing as integrity test. The typical diffusive airflow for intact membranes is in the order of 1 – 2.5 liter per element per hour, when tested at 1 bar. For the sake of this validation report, a value of 2 liters per hour per element will be used as a base line diffusive air flow level for intact membrane elements ($Q_{air\text{-}diffusive}$). This value will be verified after installation of the membranes and the initial reading will be taken of the diffusive airflow on each skid. This initial diffusive airflow will be applied to the LRV calculations of each UF skid.

- The UCL is calculated as follows:

$$UCL_{monitored} = \frac{Q_p \times 38.914 \times TMP^{-0.7224}}{10^4} + Q_{air\text{-}diffusive}$$

$$UCL_{monitored} = \frac{48.6 \times 38.914 \times 0.9^{-0.7224}}{10^4} + (2x16/1000)$$

$UCL_{monitored}$ = 0.236 m^3/hr or 236 l/hr

- The LVR for this UCL is calculated as follows:

$$LRV = \log \frac{Q_p \times 38.914 \times TMP^{-0.7224}}{Q_{air\text{-}monitored} - Q_{air\text{-}diffusive}}$$

$$LRV = \log \frac{48.6 \times 38.914 \times 0.9^{-0.7224}}{0.236 - 0.032}$$

LVR = 4.00 log removal for Cryptosporidium

- The alarm CL is calculated as follows:

$$CL_{monitored} = \frac{Q_p \times 38.914 \times TMP^{-0.7224}}{10^{4.5}} + Q_{air\text{-}diffusive}$$

$$CL_{monitored} = \frac{48.6 \times 38.914 \times 0.9^{-0.7224}}{10^{4.5}} + 0.032$$

$CL_{monitored}$ = 0.097 m^3/hr or 97 l/hr

5.2.3 Continuous indirect integrity monitoring

As indicated in the *USEPA Membrane Filtration Guidance Manual (2005)* and DHS advice, direct integrity tests are extremely sensitive and can be used to verify the accredit log removal values, however, they are undertaken only once a day (because they require system shutdown) and thus, do not verify the membrane system's integrity for all the duration of the system's operation. Continuous monitoring using indirect methods does provide real-time indication of membrane integrity, albeit with generally less sensitivity. Consequently, the advantages of the direct and indirect integrity monitoring approaches are complementary, and both are required part of a comprehensive integrity verification program.

According to the USEPA Membrane Filtration Guidance Manual (2005), the criteria for indirect integrity monitoring include:

- Filtrate of each membrane unit must be monitored independently.
- Indirect integrity monitoring on the filtrate of each membrane unit must be continuous (i.e., at a frequency no less than once every 15 minutes)
- Two consecutive excursions above a pre-established, performance-based upper control limit must trigger direct integrity testing
- all excursions above the control limit that trigger direct integrity testing must be reported to the State on a periodic basis

The following continuous indirect integrity monitoring are the most common methods that can be utilised:

- Turbidity monitoring. Turbidimeters are in widespread use throughout the water industry, and the turbidity data generated by these instruments is broadly recognized as a meaningful gauge of water quality. As such, turbidity measurements have been used as an indicator of finished water quality for previous recycled and surface water regulatory requirements. However, turbidity monitoring is less sensitive to smaller integrity breaches than particle counters or particle monitors.
- Particle counting and particle monitoring. The ability of particle counters to yield resolution information may help to optimize the usefulness of this technique for detecting potential integrity breaches. Any significant increase in the number of particles exceeding 3 mm in size may indicate that a breach allowing the passage of *Cryptosporidium* sized particles may have occurred. While particle counting and particle monitoring is more sensitive to smaller integrity breaches than conventional turbidimeters, they have disadvantages such as imprecision, susceptible to errors and being more expensive.
- Fyansford Utility has requested both methods of monitoring are to be included in the installation.
- Control limits

For indirect integrity monitoring methods the UCL is simply designed to serve as a general indication that a system integrity breach may have occurred. The *USEPA Membrane Filtration Guidance Manual (2005)* suggests the following UCL for Continuous indirect integrity monitoring:

Turbidity

- Continuous filtrate turbidity monitoring on each membrane unit is required with an upper control limit of 0.15 NTU. Because most membrane filtration systems consistently produce filtrate well below 0.15 NTU, a sustained high turbidity event with filtrate readings above 0.15 NTU may suggest a potentially serious integrity problem. Consequently, the LT2ESWTR requires that two consecutive filtrate turbidity readings above 0.15 NTU on any membrane unit trigger immediate direct integrity testing on that unit. If the unit in question passes the triggered direct integrity test, the unit may continue in production. However, if the unit fails the direct integrity test, further diagnostic testing and repair of any integrity breach(es) would be required. The unit may only be returned to service upon passing a direct integrity test.
- Alarm control unit can be set at 0.10 NTU in which a filtrate turbidity reading exceeding 0.10 NTU triggers increased monitoring frequency.

Particle counting and particle monitoring,

Absolute upper control levels may be used without a lower, relative CL (e.g., the 95-percent confidence interval of the previous month's data) provided the absolute CLs are sufficiently conservative and established using an approved scientific methodology. However, since particle count and particle monitoring data can vary significantly between two different instruments, site-specific CLs must be established when particle counting or particle monitoring is used as an alternative method of continuous indirect integrity.

5.2.4 Conclusions

Removal credits

Based on the above testing information, we are proposing the following pathogen removal credit to the Norit X-Flow UF membrane:

Target organism	Removal credit
Giardia lamblia	4-log
Cryptosporidium	4-log
Virus	3.9 log

Control limits & operational data

Table 5, X-Flow UF membrane Operating & Quality Control Parameters

Operating parameter	Maximum value
Flux	76 l/m^2/hr
Transmembrane pressure (TMP)	0.9 bar
UCL for monitored air flow during DIT[1]	236 l/hr
Alarm CL for monitored air flow during DIT[1]	97 l/hr
Turbidity UCL	0.15 NTU
Turbidity alarm CL	0.1 NTU
Particle counting and particle monitoring[2]	95% confidence interval of the previous month's data

Notes:

1) This is determined based on 2 l/hr per membrane as a base line diffusive air flow level as recommended by Norit. This will be verified by site testing following installation.
2) Particle counting and particle monitoring maybe required depending on available studies of the sensitivity of turbidity to detect small integrity breaches in the X-Flow UF membrane.

5.3 UV disinfection

The DHS requires that the approach used to validate UV treatment equipment is consistent with those outlined in the USEPA Ultraviolet Disinfection Guidance Manual for the final Long term 2 enhanced surface water treatment rule 2006 (UVDGM 2006).

We are proposing to use the Orica UV disinfection for the proposed Fyansford Utility WWTP. This is a non-contact system where the UF treated permeate would flow through Advanced Fluoropolymer tubes (AFP840) and the UV lamps and sensors are external to the permeate flow. This arrangement offers significant operating advantages in terms of faster lamp replacements and minimal cleaning requirements.

This system has been independently tested and validated according to the UVDGM by Water Futures Pty Ltd. Highlights of their validation report, which is provided in Appendix 7 are presented below.

5.3.1 Key elements of the validation report

Overview of the validation approach

The validation approach mainly involved three steps according to the UVDGM 2006:

- Part A: Establishing the UV sensitivity of a challenge microorganism (MS2 was used) in a collimated beam testing (CBT) apparatus. Part B: At the same time, dosing UV reactors with the challenge microorganism and measuring the influent and effluent concentrations.
- Calculating the UV dose applied to the challenge microorganism in the UV reactors using the UV dose sensitivity of the challenge microorganism and the degree of inactivation measured in the UV reactors. This gives the reduction equivalent dose (RED) for the challenge microorganism.
- Adjust for uncertainties to convert the RED into pathogen inactivation estimates.

Experimental design

- The reactor control strategy was Calculated Dose allowing both UV intensity and flow rate to vary. Lamp power was fixed and was not a variable with the reactor design. The purpose of the validation was to relate a calculated dose that would be predicted as the output of an algorithm that took UV intensity, UV transmissivity and flow rate as inputs. The reactor was set up as two stages in series. The first and second stages each contained independent lamp banks. There were three sampling points: the effluent samples from the first stage of lamp banks represented the influent samples for the second stage.
- The dynamic range of conditions tested, within which the calculated dose algorithm is validated, is given in Table 6. Note that there is some conservatism in relation to lamp age and the blackening of the internal walls of the reactor.

Collimated beam testing

- Collimated beam testing was undertaken on each water type on each day of experimentation in accordance with UVDGM protocols. Collimated beam tests were undertaken on each day of testing at 0, 20, 40, 60, 80 and 100 mJ/cm^2. Over the three days of testing, three UVT values were tested: 90, 80 and 60% for potable water and 60, 50 and 40% for wastewater.
- Regression analysis with removal of terms that were not significant was used to derive the dose-response relationships using regression for both potable water and wastewater at the three different UVT levels tested. The position of the mean UV dose-response curve for the MS2 phage stock solution used lay within the expected range recommended

by the UVDGM (the 95- percent prediction interval), as shown in Figure 6. The full results of this analysis are presented in the UV testing report in Appendix 7.

- The predicted dose-response relationships were compared with the observed data and the uncertainty for the dose-response relationships (UDR) were calculated according to the UVDGM. Since all UDR values were > 30%, UDR was included in the uncertainty in validation (UVAL) term. Individual UDR values could be used for defining specific reactor log credits for tight operating ranges.

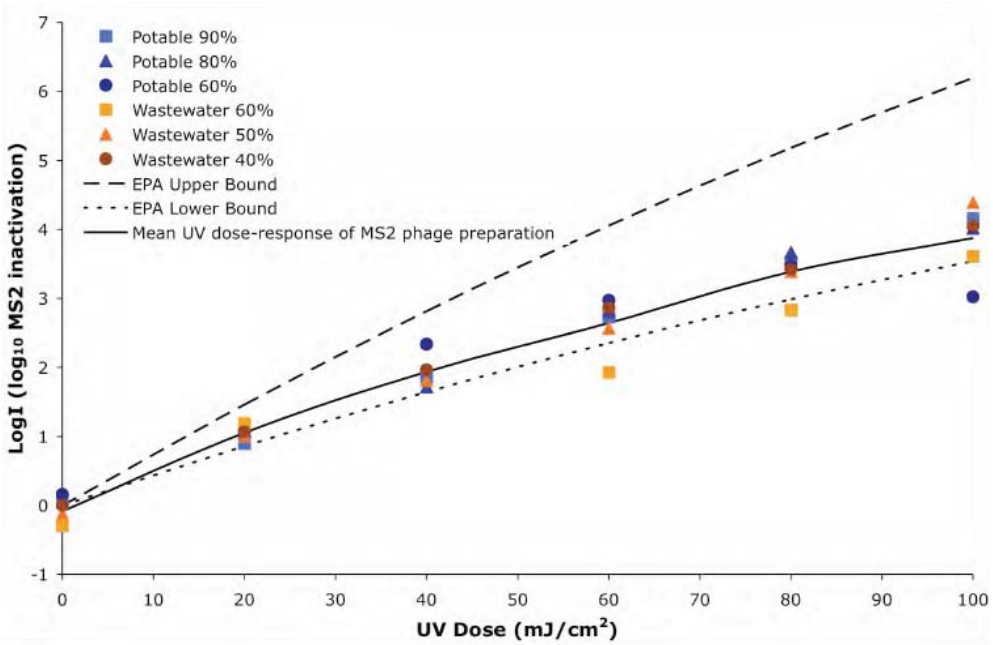


Figure 6, UV dose-response of MS2 from the collimated beam testing work

Table 6, Validated dynamic range of parameters tested

Item	Conditions tested	Range validated
Water types	Conventionally treated drinking water Conventionally treated wastewater	Water Wastewater
UVT for water	61.2, 80.9 and 91.3%	61.2 to 91.3 The water UVT range would apply to high UVT tertiary filtered wastewater
UVT for wastewater	40.3, 49.8 and 62.5%	40.3 to 62.5%
Flow tube diameters	60 mm 89 mm	60 mm 89 mm
Flow rate per tube for 60 mm	1.1, 2.3 and 4.2 l/s	1.1 to 4.2 l/s
Flow rate per tube for 89 mm	2.4, 4.4 and 8.1 l/s	2.2 to 8.1 l/s
Lamp failure	All lamps on	All lamps on
Conservative lamp safety factor	Aged lamps all over 8,000 hours	Average lamp age of up to 8,000 hours
Conservative wall safety factor	Blackened inside walls	Stainless steel clean, unclean or blackened inside walls

Biodosimetry

- Biodosimetry was undertaken, which measures laboratory surrogate endpoint and correlates it with the radiation dose. The data results of the Biodosimetry observations were analysed according to the UVDGM methodology. Two types of equations were derived from the data and combined with the dose-response equations. These two types of equations were:
  i. Control equations that use UVI (UV intensity), UVT (UV transmissivity) and flow rate as independent variables to predict calculated (RED) reduction equivalent dose; and
  ii. Design equations that use UVT and flow rate as independent variables to predict calculated (RED) reduction equivalent dose.
- The Validation Factor (VF) was determined using a range of input data as described in the UVDGM. The following sets out how each component was derived:
  i. The RED Bias (BRED) is set at 1.0, suitable for defining the RED applicable to viruses (UVDGM Appendix G) for all UVTs and all log reduction values. For Cryptosporidium, BRED is determined based on Appendix G of the UVDGM on a case-by-case basis for the minimum UVT and log reduction designed
  ii. The uncertainty of validation (UVAL) is derived from the uncertainty in inactivation (UIN), the uncertainty in the dose-response relationship (UDR) and uncertainty in the UV sensor readings (US).
  iii. Inactivation uncertainty (UIN) needs to be derived each time. The key data are the standard deviation and the value of n from which the standard deviation was derived in comparing the calculated with the measured dose for each determination. These data are shown in the body of the testing report for design and control purposes.
  iv. Dose-response uncertainty (UDR) was derived and the highest values observed, being 100.37% and 100.88% were used in calculating UVAL for potable water and wastewater, respectively. In reactor design and operation, alternative values may be used where these fit better to the specific range.
  v. UV sensor uncertainty (US) was derived from the biodosimetry results except the UV intensity (UVI) values from the UV sensors which were derived from a static run of the same test rigs shortly after the biodosimetry. The UVI values were obtained by running water through the test rig at the UVT levels representing those used during the biodosimetry for both water and wastewater. Each duty UV sensor was removed and replaced with three reference sensors to allow for the determination of the UV sensor uncertainty as described in the UVDGM.
- The data presented in this validation report can be used to support the design, and the assignment of log credits, to specific reactors. A simple calculation worksheet has been set up to enable the calculation of RED values for design and control purposes as well as the inactivation log credits for regulatory purposes. The calculation worksheet takes into account site-specific information on flow rate, UVT range, water type, target pathogen for log credit, log credit required, etc. Log reductions are additive for multiple stages, e.g. four stages can be designed based on doubling the two stage reactor predictions.

Quality assurance and quality control

The uncertainties assigned to each measurement are provided in the body of the report (Table 7-1) along with a summary of the derivation of those uncertainties and a comparison with the default criteria given in the UVDGM.

5.3.2 Calculation of the log inactivation credit

The information provided in the validation report of the Orica AFP840 UV disinfection system by Water Futures 2008 was used to calculate the pathogen inactivation credits for the proposed Orica AFP840 UV system at Fyansford Utility WWTP as follows:

- UV system design information include:

UVT is 80% (assumed for highly treated mainly residential wastewater using MBR and UF before UV disinfection).

Maximum design flow is 600 kL/day or 7.6 l/s (assuming 22 hours operation/day)

- Step 1: Calculate RED design equation specific to the challenge UV validation test

  From Table 6-4 of the validation report, look up relevant equation for potable (60mm, 2 stages). Potable was used because the UF permeate that will be disinfected through the UV system would have high UVT and is closer in quality to potable than conventionally treated wastewater considered in the validation report. The following equation is used:

  Log**RED** = 0.851 x log(1/flow) + 1.079 x logUVT

  Log**RED** = 0.851 x log(1/4) + 1.079 x log80 = 1.541

  Validated **RED** dose is 34.8 (mJ/cm^2)

- STEP 2: Calculate the Uncertainty of Validation

  $\mathbf{U_{VAL}}$ is the uncertainty in validation, calculated according to Figure 5.5 of the UVDGM 2006

  $\mathbf{U_S}$ = Uncertainty of sensor value = 6.7%, which is the average of values in Table 6-7 of the Erica UV system validation report

  $\mathbf{U_{DR}}$ = Uncertainty of the fit of the dose-response curve = 100.37% according to Table 5-5 of the Erica UV system validation report for potable (combined).

  $\mathbf{U_{IN}}$ = Uncertainty of interpolation. $\mathbf{U}_{IN}$ = (t x SD/**RED**) x 100% (Equation 5.15 of UVDGM 2006)
  Where:
  t is the t-statistic at a 95% confidence level = 2.09 according to Table 6-6 of the Erica UV system validation report for potable (60mm, 2 stages)
  SD is the Standard deviation of the differences between the test RED and the RED calculated using the dose-monitoring equation for each replicate = 17.2 according to Table 6-6 of the Erica UV system validation report for potable (60mm, 2 stages).
  $\mathbf{U}_{IN}$ = (2.09 x 17.2/34.8) x 100% = 103.4%

  $\mathbf{U}_{VAL} = (U_{IN}^2 + U_{DR}^2)^{1/2}$ Using Figure 5.5 of the UVDGM 2006 as a decision tree with $\mathbf{U_S}$ < 10% and $\mathbf{U_{DR}}$ > 30%

  $\mathbf{U}_{VAL} = (103.4^2 + 100.37^2)^{1/2} = 144.1\%$

- STEP 3: Calculate the RED Bias

  $\mathbf{B_{RED}}$ is the RED bias factor, which can be estimated from Appendix G of the UVDGM 2006

  Challenge UV sensitivity (mJ/cm^2/logI) = 23.2 according to Table 5-4 of the Erica UV system validation report for potable (combined).

  UVT is ≥80% and the target inactivation credit of 2.5 for cryptosporidium.

  $\mathbf{B_{RED}}$ = 2.72 from Table G.4 for 2.5-log Cryptosporidium inactivation credit

- STEP 4: Determine the Validation Factor

  VF is the Validation Factor, which accounts for the bias and uncertainty associated with validation testing

  $\mathbf{VF} = \mathbf{B}_{RED}$ x (1+ $\mathbf{U}_{VAL}$/100) (Equation 5.13 of UVDGM 2006)

  VF = 2.72 x (1+ 144.1/100) = 6.64

- STEP 5: Calculate the Validated Dose

D_{VAL} =**RED**/**VF** (Equation 5.16 of UVDGM 2006)

D_{VAL} = 34.8/6.64 = 5.2 mJ/cm^2

The validated dose calculated above is for a 2-stage Orica AFP840 UV reactor. To achieve the required 2.5 log inactivation, the validated UV dose should be equal or greater than 8.5 mJ/cm^2 according to Table 1.4 of the UVDGM 2006. Thus, a 4-stage Orica AFP840 UV reactor will be used whereby the validated UV dose is calculated as follows:

D_{VAL} = 5.2 x 2 = 10.4 mJ/cm^2

5.3.3 Operational requirements & critical control points

Table 7, Orica UV Disinfection System Operating & Quality Control Parameters

Operating parameter	value
Peak flow rate	4 l/s (2 required)
Validated UV dose	> 8.5 mJ/cm^2
# lamp stages/reactors	4 using 60mm dia AFP tubes to carry the process flow in serpentine arrangement in a column
Max Pressure	450 kPa
UVT%	Min of 80%

5.3.4 Log-removal credit

Based on the above testing information and calculations, we are proposing the following pathogen removal credit to the proposed Orica AFP840 UV disinfection system:

Target organism	Removal credit
Giardia lamblia	2.5-log
Cryptosporidium	2.5-log
Virus	negligible

5.4 Chlorination

5.4.1 Calculating log inactivation for chlorination

The approach used to validate log reductions based on chlorination system is consistent with those outlined in the *USEPA Disinfection Profiling and Benchmarking Guidance Manual (1999)*. The CT method was used to evaluate the amount of chlorine disinfection the Fyansford Treatment Scheme would need to achieve the 4-log removal of virus required for compliance under the EPA criteria. CT is a measure of disinfection effectiveness and is defined as disinfectant residual concentration (C in mg/L), multiplied by contact time (T in min). CT values for virus inactivation have been derived using studies traditionally applied on surface waters, however, since the recycled water before chlorination would be highly treated using MBR, UF, partially through RO and UV, it is considered acceptable to apply these CT values to recycled water.

Determining CT values

CT values corresponding to 3-log *Giardia* and 4-log viral inactivation were used as the basis for determining the estimated log inactivation achieved by chlorine disinfection within the Fyansford plant chlorine contact tank on any given day. CT values for *Giardia* were used for *Cryptosporidium* as CT values for *Cryptosporidium* were not available in the *USEPA guidance manual for disinfection profiling and benchmarking.* Operational information that was used to determine CT values from the CT tables outlined in the *USEPA Guidance Manual for Disinfection Profiling and Benchmarking* is outlined in Table 8 below. Note that the operational information used was conservative to ensure that final inactivation was for worst case scenarios.

Table 8, Operational information for calculating CT values

Operational Parameter	Value
Disinfectant type	Chlorine
pH	6.5 - 8
Temperature	5ºC
Peak hourly flow rate	8 L/sec (127 gpm)
Chlorine contact tank volume	15.52 KL (4,100 Gallons)
Residual disinfectant concentration	0.6 mg/L

Determining contact time using baffling factors

Baffling factors (T_{10}/T) according to specific baffling classifications are outlined in the *USEPA guidance manual for disinfection profiling and benchmarking.* These are outlined in Table 9 below.

Table 9, Baffling factors for chlorine contact tanks

Baffling Condition	Baffling factor (T_{10}/T)	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra basin baffles
Average	0.5	Baffled inlet or outlet with some intra-basin baffles
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders
Perfect (plug flow)	1.0	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra basin baffles.

The chlorine contact tank will be designed to meet the conditions required for “Average” baffling condition. Therefore a baffling factor of 0.5 was applied in estimating the contact time (T_{10}) required for estimation of log inactivation. Contact time (T_{10}) is calculated using the theoretical detention time (TDT), which is determined from the following:

- **TDT = (V/Q)**

- Where V= volume of the contact basin = 4,100 gallons

  Q = Peak hourly flow rate = 127 gallons per minute

- **TDT = (4,100/127)**

  = 32.28 minutes

The baffling factor is then applied to the TDT to determine the contact time (T_{10}).

- **T_{10} = TDT x Baffling Factor (T_{10}/T)**
- **T_{10} =32.28 x 0.5 = 16.14 minutes**

Estimated log inactivation requires the T_{10} calculated above along with water temperature, pH and the residual chlorine concentration expected within the contact tank. This is calculated using the following equations:

- Estimated log inactivation of *Cryptosporidium* = 3.0* CT_{actual}/ $CT_{3\text{-log, Giardia}}$
- Estimated log inactivation of adenovirus = 4.0* CT_{actual}/ $CT_{4\text{-log, virus}}$

CT_{actual} is calculated using the following equation:

- **CT_{actual} = (residual disinfection concentration) x T_{10}**
- **= 0.6 mg/L x 16.14 minutes**
- **= 9.68 mg-min/L**

Standard CT values to inactivate 3-log Giardia ($CT_{3\text{-log, Giardia}}$) and 4-log viruses ($CT_{4\text{-log, virus}}$) were sourced from Tables 3-4 and 3-5 or Appendix C of the *USEPA guidance manual for disinfection profiling and benchmarking* for the operational conditions expected in the chlorine contact tank.

- **Required $CT_{3\text{-log, Giardia}}$ for pH = 8.0, Temperature = 5ºC and Cl_2 residual = 0.6 mg/L**
- **$CT_{3\text{-log, Giardia}}$ = 204 mg-min/L**
- **Required $CT_{4\text{-log, virus}}$ for pH = 6.0 – 8.0, Temperature = 5ºC and Cl_2 residual = 0.6 mg/L**
- **$CT_{4\text{-log, virus}}$ = 8 mg-min/L**

Estimation of the log inactivation calculations based on CT values is outlined below:

- **Estimated log inactivation of *Cryptosporidium*** **= 3.0* CT_{actual}/ $CT_{3\text{-log, Giardia}}$**

  = 3.0*9.68/204

  = 0.14

- **Estimated log inactivation of adenovirus** **= 4.0* CT_{actual}/ $CT_{4\text{-log, virus}}$**

  = 4.0*9.68/8

  = 4.84

5.4.2 Operational and monitoring requirements

- The main control limit for disinfection by chlorine is CT, which can be directly related to log inactivation for virus as presented in Appendix C of the *USEPA guidance manual for disinfection profiling and benchmarking*. The critical limit of free chlorine residual to achieve CT that produces 4 log inactivation of virus is 0.5 mg/L. However, the above

calculations were based on 0.6 mg/L of free chlorine, which produces 4.8 log inactivation, thus the 0.6 mg/L free chlorine can be considered an alarm (low) control limit.

- The alarm and critical control limits were calculated based on certain design assumptions outlined in Table 8 above. Thus, such variables are also considered as critical control limits.
- The contact time for the calculation of CT will be determined through tracer studies according to Appendix D of the *USEPA guidance manual for disinfection profiling and benchmarking*. The contact time of mixing basins and storage reservoirs used in calculating CT should be the minimum detention time experienced by 90 percent of the water passing through the unit.
- The CT would be monitored through measurement of the free residual chlorine at a level that corresponds to the validated detention for the system. In this respect, as calculated above, 0.6 residual of free chlorine would produce 4.8 log inactivation of virus. 0.5 residual of free chlorine would produce 4.0 log inactivation of virus.
- Residual is measured online along with temperature and pH at the outlet of the chlorine contact tank. Chlorine dosing will be using automatic dosing pumps, which stop when the residual free chlorine reaches the required limit. If the monitored residual chlorine is below the required limit but not less than the absolute limit for compliance (i.e between 0.5 and 0.6 mg/L free chlorine), then an alarm will be activated that requires investigation. If the monitored residual chlorine is below 0.5 mg/L free chlorine, then the system shuts down until the problem is rectified.
- The residual is also measured at the second disinfection application point, which is the recycled water storage tank that feeds the recycled water distribution system.

5.5 Overall validated log-removal of pathogens

Table 10 below summarises the total log reductions expected from the Fyansford water treatment system. It is expected that these log reductions will be verified following construction and commissioning of the treatment train through ongoing monitoring systems. It is assumed that bacterial criterion is achieved through respective log reductions in virus and *Cryptosporidium.*

Table 10, Expected microbial log reductions of the selected treatment system

Pathogen	Class A Target Log Reduction	Fyansford Proposed Water Treatment Process					
		MBR	UV	UF	RO	Cl	Total
Bacteria	<10 *E.coli*/100ml (8 - log)	- -	-	-	-	-	<10 *E.coli*/100 ml (8-log)
Adenovirus/MS2	7 - log	-	negligible	3.5		4	7.5
Cryptosporidium:	6 - log	-	2.5	4		0.14	6.64

6 Operational Monitoring and Process Control

This section covers the operational monitoring and process control to be implemented to formalise the activities which are essential for ensuring that recycled water of an acceptable quality is consistently provided.

Sirex will ensure that process-control programs specifying detailed operational factors are developed to ensure that all processes and activities are carried out efficiently and effectively. Examples of specific process-control programs include:

- Descriptions of all preventative measures and their functions
- Documentation of effective operational procedures, including identification of responsibilities and authorities
- Establishment of a monitoring protocol for operational performance, including selection of operational parameters, such as target criterion and critical limits, and the routine review of data
- Establishment of corrective actions to control excursions in operational parameters
- Development of requirements for use and maintenance of suitable equipment
- Development of requirements for use of approved materials and chemicals in contact with recycled water
- Establishment of procedures for restricted end uses
- Establishment of procedures for activities undertaken by users of recycled water at application sites (particularly when end use preventative measures are relied on to minimise the risk to acceptable levels)

Effective implementation of process-control programs will be undertaken through the training and awareness initiatives outlined in Section 10.

6.1 Monitoring and Corrective Actions

Operational monitoring protocols will be developed to assess and confirm the performance of preventative measures through a planned sequence of observations and measurements. Operational monitoring will include the following key elements:

- Development of operational monitoring plans from source to point of use and beyond, detailing strategies and procedures
- Identification of the parameters and criteria to be used to measure operational effectiveness and where necessary, trigger corrective actions
- Ongoing review and interpretation of results to confirm operational performance.

Operational monitoring will also include regular observational monitoring which will include:

- Regular inspections of industrial waste facilities, sewer integrity and plant equipment
- Monitoring of application methods, timing of irrigation, access controls and signage.

Procedures will also be developed to re-establish process control immediately in situations where alert criteria or critical limits are exceeded/not met. These procedures will include instructions on required adjustments, process-control changes and additional monitoring.

The tables below provide preliminary procedures and corrective actions for identified CCPs along with potential critical and alert limits.

Ultra filtration

CCPx	Flux	Trans membrane pressure (TMP)	Monitored air flow during DIT	Turbidity	Particle counting
Critical limits/Alert limits					
Alert			97 l/hr	0.1 NTU	
Critical	76 l/m^2/hr	0.9 bar	236 l/hr	0.15 NTU	95% conf. int. of previous month data
Monitoring procedures					
What	Total flow to UF	Trans membrane pressure	Air flow during DIT	Turbidity	
How	Flow meter	Pressure meter		Turbidity meter	
When	Continuous	Continuous	Once a day	Continuous	
Where	Upstream of UF	UF vessel		UF permeate	
Who	Automatic	Automatic		Automatic	
Corrective actions					
What					
How					
When					
Where					
Who					
Verification records					

UV disinfection			
CCPx	Peak flow rate	Max. pressure	UVT%
Critical limits/Alert limits			
Alert			
Critical	4 l/s per reactor	450 kPa	80%
Monitoring procedures			
What			UVT
How			UVT meter
When			Continuous
Where			
Who			
Corrective actions			
What			
How			
When			
Where			
Who			
Verification records			

Chlorination
CCPx
Critical limits/Alert limits
Alert
Critical
Monitoring procedures
What
How
When
Where
Who
Corrective actions
What
How
When
Where
Who
Verification records

6.2 Standard Operating Procedures

A draft Operation and Maintenance ("O&M") manual will be prepared by Sirex for the FUPLS (copy is attached in Appendix 20). The O&M manual will be prepared and finalised during the commissioning phase. The O&M manual will provide a range of standard operating features including daily run checks. The following is an example standard operating procedure for daily run checks on the MBR plant by Sirex operators:

Fyansford Daily Maintenance
1. FILL OUT SYTEM LOG SHEET AND VERIFY THAT THE OPERATING SETTINGS ARE NORMAL.
2. VISUALLY CHECK ALL SYSTEMS, INCLUDING ALL CHEMICAL STORAGE CONTAINERS AND CHEMICAL PIPING SYSTEMS, AS WELL AS ALL UNIT PIPING, PRESSURE AND FLOW INSTRUMENTS, SAMPLE TAPS AND FITTINGS, TUBING AND TANKS AND REPAIR AS NECESSARY.
3. COLLECT SAMPLE FROM AND MEASURE MLSS CONTENT. IF MLSS EXCEEDS 12,000MG/L SOME OF THE SLUDGE FROM THE BOTTOM OF THE MBR MUST BE REMOVED.
4. VISUALLY INSPECT THE AIR DISTRIBUTION IN THE MBR AND PERFORM AERATOR WASH PROCEDURE IF UNEVEN AIR DISTRIBUTION IS OBSERVED.

7 Verification Monitoring

8 Prerequisite Programs

A number of prerequisite programs are in place to ensure optimal process operation underpins the effectiveness of the preventative risk management system. These include:

- Trade waste management
- Operation and maintenance procedures
- Quality assurance for installation of treatment components (e.g. configuration of UV reactors, factory pressure tests for membrane systems, product specifications for replacement parts)
- Calibration of monitoring instrumentation
- Chemical quality assurance
- Overarching quality management systems that the RWQMP will be linked to.

Need to get further detail on these programs and any others which may exist.

9 Incidents and Emergencies

9.1 Incident Management and Emergency Response Protocols

A number of incidents and emergency situations have been outlined through the application of the HACCP principles to the Fyansford Utility scheme. This Section will identify all realistic emergency scenarios and will detail incident and emergency protocols specific to the production and supply of recycled water including response actions, roles and responsibilities and communication arrangements. Relevant incidents will be those which may affect human health and the environment, such incidents may include:

- Non-conformance with guideline values or water quality objectives
- Incidents that increase the levels of potentially harmful contaminants or cause failure of treatment systems (including spills, illegal discharges or incorrect dosing of chemicals).
- Toxic algal blooms in recycled water storages
- Unauthorised use of recycled water
- Recycled water – potable water reticulation cross connection
- Other specific incidents or emergencies relevant to the dual pipe scheme.

Fyansford Utility will include incident management and emergency response protocols within its operation and maintenance manuals. These protocols will be defined through the development of the HACCP and will be developed to ensure that public and environmental health risks are managed efficiently and effectively. The protocols will be developed in consultation with the DHS, EPA and other relevant authorities and will be consistent with existing emergency response regulation.

Key areas to be addressed in the incident management and emergency response protocol include:

- Response actions
- Responsibilities of individuals or groups, both internal and external to the organisation
- Plans for alternative water supplies
- Mechanisms for increased health or environmental surveillance.

A corrective action plan has been established based on the Critical Control Points (CCP's) developed through the HACCP process. The objectives for the corrective action plan are to:

- Bring processes back under control as soon as possible
- Where possible dispose of any unsafe water before it can reach the end user
- Generate improvement plans to avoid recurrence of critical limit exceedance.

10 Employee Awareness and Training

Employee awareness and training are essential for the successful operation of a recycled water system. Employees require a sound knowledge base so that they can make effective operational decisions. The development and maintenance of a sound knowledge base requires training in the methods and skills associated with the operations of a recycled water system. This section outlines the employee training needs and programs intended for the Fyansford Utility staff. All training will be documented and recorded to identify progress and future training needs. Training of all staff will be ongoing as part of the review of environmental and health approval documentation.

10.1 Operations Staff

Treatment plant and associated processes

Operators and contractors working within the treatment plant and associated processes (pipeline, storage and irrigation) will be appropriately skilled and trained in the management and operation of recycled water supply systems and will have completed Certificate 3 in Water Industry Operations, a nationally accredited course. Other methods intended for increasing employee awareness and training will include induction and education programs, newsletters, guidelines, manuals, notice boards, seminars, briefings and meetings. Relevant training areas which will be addressed include through such methods includes:

- General water quality
- Water microbiology and chemistry
- Soil and groundwater chemistry
- Recycled water treatment
- Stormwater collection and treatment
- Trade waste control
- Irrigation management (for irrigation of the Fyansford Green using recycled water)
- Hydraulic, nutrient and contaminant balances at sites of use or discharge
- Application of plumbing codes relating to recycled water and dual water supply systems
- On-site treatment of sewage and greywater
- Operation of filtration plants
- Disinfection system operation
- Distribution management
- Sampling, monitoring and analysis of recycled water, soils, groundwater and surface water.
- Interpretation and recording of results
- Risk management
- Equipment maintenance
- Incident management and emergency response
- Document control

Initially an Operation and Maintenance Manual will be developed to inform and educate staff on proper operation of the treatment plant and associated processes. Training courses in the

operation and maintenance of the treatment plant will be developed and run prior to commissioning of the system. These initial courses will include instruction on:

- HACCP Introduction and Responsibilities
- HACCP Response to exceedance of Critical Limits
- Process overview and requirements
- Pumps
- Compressors
- UV System
- Chemical dosing system
- Sampling systems and analysers
- Control system and SCADA
- Maintenance requirements for the above

10.2 Office Based Staff

Instruction and documentation will be provided to office based staff to educate them about the appropriate and prohibited uses of recycled water. Instruction and protocols will also be provided to staff prior to plant commissioning which outlines procedures for notifying customers and authorities of any incidents or emergencies.

11 Documentation and Reporting

This section will outline the documentation and reporting procedures and initiatives to be implemented at the Fyansford Utility scheme.

11.1 Documentation

Appropriate documentation will be developed for the Fyansford Utility scheme. It will provide the foundation for implementing and maintaining effective recycled water quality management systems. This documentation will include:

- CCP monitoring results and analyses
- Breaches of critical limits and corrective actions taken
- Verification monitoring
- Incidents and emergencies and corrective actions taken
- Inspection and maintenance activities relevant to water quality
- Preventative measures and their purpose
- Operational procedures for relevant activities
- Operational monitoring protocols, including parameters and criteria
- Schedules and timelines
- Data and records management requirements
- Corrective actions to be implemented when required
- Maintenance procedures
- Responsibilities and authorities
- Internal and external communication and reporting requirements

All documentation will:

- Demonstrate that a systematic approach is established and is implemented effectively
- Develop and protect the organisations knowledge base
- Provide an accountability mechanism and tool
- Satisfy regulatory requirements
- Facilitate reviews and audits by providing written evidence of the system
- Establish due diligence and credibility.

Documentation will also be developed in such a way which to provide a basis for effective communication within the organisation as well as to the community and to various other stakeholders as necessary. A document control system will also be established to ensure that the most recent version of an appropriately approved document is in use.

All documentation will be stored so they are visible and readily available to operators and end users where required. Systems and protocols will be developed to ensure that documentation is read, adequately understood and adhered to.

Simple, efficient and focused documentation and record keeping systems will be developed and implemented where documentation requires record keeping of large amounts of data (such as

water and environmental quality monitoring, validation and verification, performance evaluation, audits and reviews etc).

All documentation will be periodically reviewed and revised to ensure that they are kept up to date. A computer based documentation system will be considered due to faster and easier access, distribution, back up and updating.

11.2 Reporting

Procedures complete with definition of responsibilities and authorities will be established for regular reporting. It is intended that reporting will be both internal and external and will summarise at least the following areas:

- Monitoring data
- Performance evaluation
- Incidents
- Maintenance
- Auditing and verification
- Management review

Fyansford Utility will develop specific protocols and reporting procedures to inform the EPA, DHS and other relevant agencies and stakeholders in the even of an incident or emergency (such as the supply of off-specification water to customers).

An annual report will be prepared and submitted to both the EPA and DHS. This will include:

- Summarised recycled water quality performance over the preceding year against numerical guideline values, regulatory requirements or agreed levels of service, and identification of water quality trends and problems
- A summary of soil, groundwater and surface water monitoring at application and receiving environments over the preceding year against numerical guideline values, regulatory requirements or agreed levels of service and identification of water quality trends and problems
- A summary of any system failures and the action taken to resolve them
- Specification to whom Fyansford Utility is accountable as well as all statutory or legislative requirements, and minimum reporting requirements
- Conformance as to whether monitoring was carried out in accordance with the principles of risk management outlined by the EPA and the DHS.
- A summary of audit outcomes.

11.3 Notifications

Notification procedures will be established to ensure that the Scheme Manager and/or Users are notified of any incident that potentially places public health at risk. The Environmental Health Unit of DHS will be immediately notified should any of the following occur:

- A system failure that may potentially impact on users of the recycled water
- An emergency or incident that potentially places public health at risk
- Any changes to the RWQMP or operation of the treatment process that may potentially impact achieving required water quality objectives.

12 Auditing

A periodic auditing process is to be established to ensure compliance of obligations under the RWQMP. The audit will cover actions of all stakeholders including operators, managers, users of recycled water and where appropriate, plumbers and installers of extensions to systems; and of implementation and adherence to on-site controls and use restrictions.

Internal audits will occur randomly throughout the year and will review the following:

- Staff competency
- Review of management systems and associated operational procedures and monitoring programs
- Review of records and documentation.

External audits will be required to be submitted to the EPA and DHS as part of the *Environment Protection Act 1970.* These audits are required to be undertaken by an independent third party within the first 12 months of commissioning with ongoing audit frequency to be determined by the EPA depending on the outcomes of the initial audit. External audits will be developed in accordance with AS/NZS19011:2003 *Guidelines for Quality and/or Environmental Management Systems Auditing* and will focus on confirming the implementation and results of the internal audits and will also consider the following:

- The preventative management system
- Operational activities
- Implementation of the HEMP provisions
- Recycled water quality performance
- Application of on-site controls and adherence to use restrictions
- The effectiveness of incident and emergency response or other specific aspects of recycled waster quality management
- Environmental indicators and performance
- Changes to end use, relevant guidelines, policies and legislation.

Audit results will be documented and communicated to management and staff responsible. Results of the audits will also feed into an annual review of documentation and operational procedure by the system manager.

13 Review and Improvement

All documents outlined within this RWQMP will be regularly reviewed and updated where necessary to ensure it remains relevant. The purpose of the review will be to:

- Assess overall performance against guidelines and regulatory requirements
- Address emerging problems and trends identified through monitoring results, internal reviews, incidents and emergencies
- Identify priorities for improving recycled water quality management, and research and development opportunities
- Incorporate management responses to emerging issues that relate to recycled water quality, and confirm whether any potential risks are being appropriately managed.

Review of the documentation and processes outlined in the RWQMP will be reviewed at least annually to encourage continual improvement of the system as a whole. Any significant changes to the HEMP and the RWQMP will be submitted for EPA approval and DHS endorsement, while minor changes will be provided to the EPA within the annual report.

14 Commissioning the RWQMP

Fyansford utility will ensure that all monitoring, critical limit alarms and corrective action within the RWQMP have been tested and verified by an independent third party upon commissioning.

Appendix 1

Fyansford Utility Operations Flow Chart

Appendix 2

Fyansford Utility Scheme Layout Plans

Appendix 3

WWTP building and plant layout plans

Appendix 4

Schematic & process flow diagrams

Appendix 5

Preliminary hazard identification & controls table

Appendix 6

UF design and validation report

Appendix 7

UV design and validation report

Appendix 8

MBR M&O Manual

KOA 00.126
September 2000

Removal of micro-organisms by ultrafiltration by X-Flow 0.8UFC M5 membranes

Effect of impaired integrity

Report 1: Challenge with *Bacillus* spores

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Effect of impaired integrity

Report 1: Challenge with *Bacillus* spores

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Contents

1 Introduction

One of the most prominent applications of ultrafiltration in drinking water treatment is for the removal of pathogenic micro-organisms. The small pore-size of the membrane-fibres (around 0.01 μm) make ultrafiltration in theory an absolute barrier against pathogenic bacteria (1-2 μm), protozoa (like *Cryptosporidium* (4 - 5 μm) and *Giardia* (8 - 18 μm)) and viruses (0.025 - 0.08 μm).
In practice, UF is not absolute, but the removal efficiency is considerable (4 - 6 logs, Lovins *et al.*, 1999; Smith & Pearce, States *et al.*, 1999, Kiwa-data; Jacangelo *et al.*, 1991; Mandra and Baudin, 1996) and exceeds that of many of the conventional treatment steps. The fraction of the smallest micro-organisms used in tests that may appear in the permeate could have passed the membrane units through a fraction of the pores with sizes similar to the sizes of these micro-organisms.
When the membrane integrity is severely impaired (i.e. in the case of broken fibres), more micro-organisms may pass through to the permeate and the removal efficiency is reduced.

As membrane integrity is of primary importance to warrant the removal efficiency of an UF-unit, the integrity should be measured in challenge-tests such as described in this report. Integrity monitoring during operation is equally essential, and may be realised by for example particle counting (Willemsen-Zwaagstra *et al.*, 1997) and/or air-water-displacement-tests (G. Turner, pers. comm.).

The aim of this study was to determine the removal of micro-organisms by ultrafiltration in a system with two membranes that are approved by the X-Flow test procedures, which incorporate a bubble test and pressure hold test and to determine the effect of breaking one, two or three of the approx. 10.000 fibres of the two membranes on the removal efficiency.

For this purpose, the membrane elements in a pressure vessel were challenged with model-organisms: *Bacillus subtilis* spores (approx. 1 μm) and MS2 F-specific bacteriophages (27 nm). The spores were used as a conservative surrogate for the larger (oo)cysts of parasitic protozoa (i.e. *Cryptosporidium parvum*-group oocyst size approx. 4 μm) and the phages are used as a surrogate for pathogenic viruses, i.e. Norwalk like viruses.

This report describes the result of the challenge tests with *Bacillus* spores. The results of the tests with phages will be reported in a follow-up report.

2 Study design

2.1 Test organisms

To determine the removal efficiency of the membrane system, the membranes were challenged with water to which spores of *Bacillus subtilis* (approx 1 μm) were added in high concentrations (approx. 10^4 per ml). *Bacillus subtilis* spores are regarded as an indicator for the removal of persistent organisms, such as *Cryptosporidium*.
The micro-organism suspensions were prepared by Kiwa in sterile water at a strength of $10^{10\text{-}11}$ per litre and transported on ice to the NMT installation at Hengelo.

2.2 Test system

The membranes that were tested were type 0.8mm UFC M5 (8 inch) membrane elements. The membrane elements were tested in a bubble-test by X-Flow according to the standard protocol. Two membranes were installed in a pressure vessel. The vessel and membranes were tested in a pressure-hold test, according to the X-Flow protocol.
The vessel was fed by a feed pump with drinking water at a flow of 7 m^3/h.
The micro-organisms were dosed into the feed water at a rate of 1 litre/h, resulting in a feed concentration of approx. $10^{3\text{-}4}$/ml.
Sampling taps were installed just prior to the pressure vessel and in the permeate line.
After the experiments the membrane elements were re-tested in a bubble test to verify the number of broken fibres after the experiment was identical to the number of broken fibres prior to the experiment.

2.3 Challenge tests

Before the onset of the challenge, the membranes were installed in the pressure vessel, flushed and deaerated and disinfected with NaOCl (200 mg/l). After flushing of the system a blank sample was taken.

Challenge 1: two intact membrane elements
The challenge was started by starting the dosing pump. After 10 minutes, a sample of the feed was taken. After 15 minutes and 30 minutes of filter-run two (duplicate) samples were taken from the permeate.
The filtration was stopped and the system was flushed, chlorinated and dechlorinated, according to the protocol in annex I.
Care was taken to keep samples and sampling materials from the feed and permeate side separate. Samples were kept on ice.

Challenge 2: one intact element and one element with one broken fibre
After this first challenge test with two intact membrane elements, one of the elements was removed from the pressure vessel and replaced by a membrane

element with one broken fibre (determined in bubble test). The installation was flushed and deaerated again and after a blank sample was taken, a challenge with spores was restarted and sampling and flushing/chlorination were performed as in challenge 1.

Challenge 3: one intact element and one element with three broken fibres
Now, the element with one broken fibre was removed and replaced with an element with three broken fibres. The preparation, challenge, sampling and flushing/chlorination were performed as in challenge 1 and 2.

Challenge 4: one intact element and one element with two broken fibres
The element with three broken fibres was removed from the pressure vessel and one of the fibres was plugged at both sides to stop the water flow through this fibre. Hence, this element contained two broken fibres where water was flowing through. Due to the longer time needed for the preparation of this challenge test, the UF had been flushed more thoroughly than after the chlorination in the previous challenge tests.

After all samples were taken, the samples were transported on ice to the Laboratory of Microbiology of Kiwa and appropriate volumes were analysed for spores of *Bacillus subtilis* by membrane filtration on Plate Count agar, according to the Kiwa Laboratory for Microbiology protocol.

3 Results & discussion

The results of the sample analysis are given in Table 1. The data of the first run indicate that the challenge experiment was performed as planned. The measured concentrations in the feed were comparable to the expected concentrations based on the concentration in the challenge suspension and the flow rates of the feed and challenge (dilution).

Table 1. Counts of Bacillus subtilis spores in the samples of the challenge tests.

Sample description	*Bacillus* spores CFU/ l
First run (intact elements):	
QA samples	
Permeate blank 1	<1
Permeate blank 2	<1
Challenge suspension	approx. 10^{11}
Challenge test	
Feed concentration	8.8×10^{6}
Permeate after 15 minutes	<1
Permeate after 15 minutes	<1
Permeate after 30 minutes	<1
Permeate after 30 minutes	<1
Second run (1 fibre broken):	
QA samples	
Permeate blank	<1
Challenge test	
Feed concentration	8.8×10^{6}
Permeate after 15 minutes	5.0×10^{3}
Permeate after 15 minutes	5.0×10^{3}
Permeate after 30 minutes	3.8×10^{3}
Permeate after 30 minutes	3.8×10^{3}
Third run (3 fibres broken):	
QA samples	
Permeate blank	<1
Challenge test	
Feed concentration	9.8×10^{6}
Permeate after 15 minutes	7.5×10^{3}
Permeate after 15 minutes	6.3×10^{3}
Permeate after 30 minutes	6.3×10^{3}
Permeate after 30 minutes	3.8×10^{3}
Fourth run (2 fibres broken):	
QA-samples	
Permeate blank	<1
Challenge test	
Feed concentration	8.2×10^{6}
Permeate after 15 minutes	1.3×10^{3}

Permeate after 15 minutes	1.3×10^3
Permeate after 30 minutes	3.8×10^3
Permeate after 30 minutes	6.3×10^3

The blank samples of the spores were always negative, indicating that the flushing and cleaning protocol was adequately removing these spores from the system.
The spore concentration in the feed was close to the concentration that could be calculated based on the concentration in the challenge suspension (10^{11}/l) and the dilution of the challenge suspension (1 l/h) in the feed water stream (7 m^3/h), indicating no significant losses of spores during the challenge. The concentration in feed water was similar in all four runs, indicating that the challenge suspension was homogeneous, as was the dosing of this suspension to the feed water in the subsequent experiments. Also the variation between the duplicate samples was within the expected range in microbiological assays.

The data were used to calculate the log-removals (= $^{10}\log(C_{feed}/C_{permeate})$; Table 2).

Table 2. Calculated log-removals of Bacillus subtilis spores during the filter-runs

Description	*Bacillus* spores
First run (intact elements)	
Permeate after 15 minutes	> 6,9 log
Permeate after 15 minutes	> 6,9 log
Permeate after 30 minutes	> 6,9 log
Permeate after 30 minutes	> 6,9 log
Second run (1 fibre broken)	
Permeate after 15 minutes	3,2 log
Permeate after 15 minutes	3,2 log
Permeate after 30 minutes	3,4 log
Permeate after 30 minutes	3,4 log
Fourth run (2 fibres broken)	
Permeate after 15 minutes	3,8 log
Permeate after 15 minutes	3,8 log
Permeate after 30 minutes	3,3 log
Permeate after 30 minutes	3,1 log
Third run (3 fibres broken)	
Permeate after 15 minutes	3,1 log
Permeate after 15 minutes	3,2 log
Permeate after 30 minutes	3,2 log
Permeate after 30 minutes	3,4 log

Sampling codes : M-002911 to M-002940
Sampling date : July 17, 2000

In general, the duplicate samples are in good agreement. Also, the differences between the samples taken after 15 and 30 minutes are small. Only in run 4, the 15 min samples yielded less spores (and hence more removal) than the 30 minute samples. The calculated log-removals were averaged to determine the average log-removal at each condition (Table 3).

The impaired integrity results in a significant reduction of the removal efficiency. The intact filters removed more than 6.9 logs of spores. Already at one broken fibre, the spore-removal was reduced to 3.3 logs. This is, however, still a very significant removal efficiency.

Table 3. Average log-removal of MS2 phages and Bacillus subtilis spores in the runs with an increasing number of broken fibres.

Condition	*Bacillus* spores (log-removal)
Intact elements	> 6,9
Second run (1 fibre broken)	3,3
Fourth run (2 fibres broken)	3,5
Third run (3 fibres broken)	3,2

There is no significant difference observed between the runs with 1, 2 or 3 broken fibres. The first broken fibre already reduced the efficiency a factor of 4000 (>6.9 logs to 3.3 logs). Assuming the removal of the water flowing through the intact fibres is still >6.9 logs, this factor is an estimate of the fraction of water that is flowing through the broken fibre. With approx. 20.000 fibres in the pressure vessel of which one is broken, this would mean that approx. 0.025% of the water flows through the broken fibre. The additional water that flows through the additional broken fibres may further reduce the efficiency with a factor of 2 (for 2 broken fibres) to 3 (for 3 broken fibres), but this factor is insignificant compared to the factor 4000 of the first fibre. This indicates that for optimal performance of membrane elements no fibres should be broken.

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October 2000

Removal of micro-organisms by ultrafiltration by X-Flow UFC M5 0.8 mm membranes

Effect of impaired integrity

Report 2: Challenge with MS2 phages and *Bacillus* spores

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Report 2: Challenge with MS2 phages and *Bacillus* spores

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Contents

1 Introduction

This is a follow-up report on the challenge tests that have been conducted in July 2000 with *Bacillus* spores. This report describes the results of challenge tests with MS2 bacteriophages and *Bacillus* spores of the 0.8mm UFC M5 membranes of X-Flow. For the study background the reader is referred to the first report.

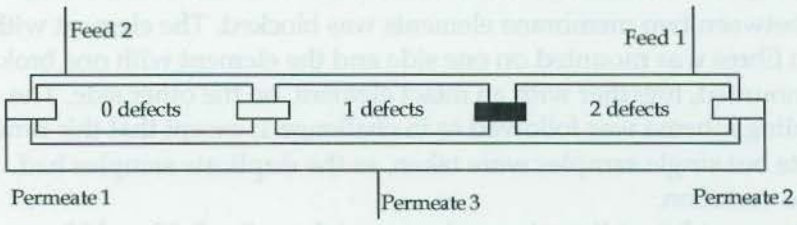
2 Study design

2.1 Test organisms

To determine the removal efficiency of the membrane system, the membranes were challenged with water to which spores of *Bacillus subtilis* (approx 1 μm) and MS2 bacteriophages were added in high concentrations (approx. 10^{6-7} per litre). *Bacillus subtilis* spores are regarded as an indicator for the removal of persistent organisms, such as *Cryptosporidium*. MS2 phages are regarded as indicator for the removal of human pathogenic viruses, such as Hepatitis A and Norwalk-like caliciviruses.
The micro-organism suspensions were prepared by Kiwa in sterile water at a strength of 10^{10-11} per litre and transported on ice to the NMT installation at Hengelo.

2.2 Test system

The membrane elements that were tested were of the type S-225-FSFC PVC containing UFC M5 0.8mm membranes. The membrane elements were tested in a bubble-test by X-Flow according to the standard protocol. Three membranes were installed in a pressure vessel.
The vessel was fed by a feed pump with drinking water at a flow of 5.5, 10.5 or 14 m^3/h. The micro-organisms were dosed into the feed water to obtain a feed concentration of approx. $10^{6-7}/l$.
In the first experiment, three intact membrane elements were mounted in the pressure vessel. The vessel was fed by a feed pump with drinking water at a flow of 10.5 m^3/h. In the second experiment, the pressure vessel was mounted with one intact element, one element with a single broken fibre and one element with two broken fibres. The permeate flowing from the element with two broken fibres (Permeate 2) was kept separate from the permeate of the two other elements (intact + one broken fibre). This was accomplished by blocking the connector of the elements (see installation scheme).



In effect, this means :

- Permeate sample 1: 1 defect in 2 modules (0.5 defects per module)
- Permeate sample 2: 2 defects in 1 module (2 defects per module)
- Permeate sample 3: 3 defects in 3 modules (1 defect per module)

The fibres were cut through completely, to mimick a worst case break.
The vessel was fed by a feed pump with drinking water at a flow of 5.5, 10.5 or 14 m^3/h. The micro-organisms were again dosed into the feed water to obtain a feed concentration of approx. $10^{6-7}/l$.
Sampling taps were installed just prior to the pressure vessel and in the permeate lines from both sides of the pressure vessel. At one side, the permeate of the element with two broken fibres was sampled (Permeate 2). At the other side, samples of the permeate from the intact element and element with 1 broken fibre was collected (Permeate 1). An additional sample was taken from the permeate line after both permeates were mixed (Permeate 3). This was the sample with 3 broken fibres.
After the experiments the membrane elements were re-tested in a bubble test to verify the number of broken fibres after the experiment was identical to the number of broken fibres prior to the experiment.

2.3 Challenge tests

Before the onset of the challenge, the membranes were installed in the pressure vessel, flushed and vented. In contrast to the challenge tests described in the first report, no chlorination/dechlorination was performed prior to and in between the challenges, since residuals appeared to inactivate the bacteriophages. After flushing of the system duplicate blank samples were taken from the feed and permeate.

Challenge 1: three intact membrane elements
The UF was run at 10.5 m^3/h. The challenge was started by starting the dosing pump. After 5 minutes, duplicate samples of the feed and of the permeate were taken. After 10 minutes and 15 minutes of filter-run this sampling scheme was repeated. Care was taken to keep samples and sampling materials from the feed and permeate site separate. Samples were kept on ice.

Challenge 2: broken fibres
One week after the challenge test with three intact membrane elements, the pressure vessel was refitted with three membrane elements. This time the connector between two membrane elements was blocked. The element with two broken fibres was mounted on one side and the element with one broken fibre was mounted, together with an intact element, on the other side. The same sampling scheme was followed as in challenge 1, except that this time no duplicate but single samples were taken, as the duplicate samples had shown little variation.
The UF was run at 5.5 m^3/h and samples were taken after 5, 10 and 15 minutes of both permeate and feed.
Subsequently, the water flow was increased to 10.5 m^3/h and samples were taken again after 5, 10 and 15 minutes of both permeate and feed. After the last sampling, the water flow was again increased, now to 14 m^3/h.

After all samples were taken, the samples were transported on ice to the Laboratory of Microbiology of Kiwa and appropriate volumes were analysed for MS2 F-specific RNA phages according to ISO 10705-1 and spores of *Bacillus subtilis* by membrane filtration on Plate Count agar, according to the Kiwa Laboratory for Microbiology protocol.
Also the feed suspension was re-tested to verify no significant die-off had occurred.

3 Results

3.1 Challenge test with intact membrane elements

The results of the sample analysis are given in Tables 1 and 2. The data indicated that the challenge experiment was performed as planned. The measured concentrations in the feed were comparable to the expected concentrations based on the concentration in the challenge suspension and the flow rates of the feed and challenge (dilution).

Table 1. Counts of MS2 phages in the samples of the challenge test with intact modules.

Sample description	*MS2 phages* PFU/ 10 ml	Removal
Intact elements		
QA samples		
Feed blank a	<1	
Feed blank b	<1	
Permeate blank a	<1	
Permeate blank b	<1	
Challenge suspension	1.30×10^{11}	
Challenge test – after 5 minutes		
Feed a	2.95×10^{6}	
Feed b	3.05×10^{6}	
Permeate a	8	5.6 log
Permeate b	6	
Challenge test – after 10 minutes		
Feed a	1.85×10^{6}	
Feed b	1.61×10^{6}	
Permeate a	42	4.6 log
Permeate b	47	
Challenge test – after 15 minutes		
Feed a	2.05×10^{6}	
Feed b	2.50×10^{6}	
Permeate a	242	4.0 log
Permeate b	197	
Spike samples	Contact time 0 hr	Contact time 2 hr
Feed a	6.05×10^{6}	3.20×10^{6}
Feed b	6.20×10^{6}	4.23×10^{6}
Permeate a	6.55×10^{6}	2.45×10^{6}
Permeate b	6.10×10^{6}	2.60×10^{6}
Backwash	4.80×10^{5}	5.0×10^{3}

The feed and permeate blanks were negative. The membrane elements were challenged with a concentration of 1.61 – 3.05 x 10^6 MS2 phages per 10 ml. Phages were found in the permeate at concentrations of 6-8 per 10 ml after 5 minutes, 42-47 per 10 ml after 10 minutes and 197-242 per 10 ml after 15 minutes, a clear trend of increasing concentrations in permeate with time. The duplicate samples showed good agreement. The log-removal was therefore calculated from the average of the duplicates (Table 1) and showed the trend of decreasing removal efficiency over time.
A plausible explanation for this cannot be given as this effect was not observed in other tests with phages with X-Flow membranes and the installation was explicitly checked on integrity before the dosing of phages started. The best estimate of the average removal efficiency during operation is based on the average concentration in the permeate. This was used to calculate the log-removal (Table 1).
The spiked control samples showed a slight reduction of phage counts in the pre-challenge feed and permeate samples but a very significant reduction of phages in the sample taken after chlorination/dechlorination. This indicates that after chlorination/ dechlorination the water still contains residuals that inactivate the MS2 phages. This is in agreement with the inactivation of phages observed in earlier challenge tests. In a separate test at Kiwa it was shown that this could not be attributed to exposure to the dechlorination compound (bisulphite) as 1.5 hrs exposure to 100 mg/l did not result in a significant reduction of the phage (or spore) count.

Table 2. Counts of Bacillus spores in the samples of the challenge test with intact modules.

Sample description	*Bacillus spores* CFU/ l	Removal
Intact elements		
QA samples		
Feed blank a	*	
Feed blank b	*	
Permeate blank a	*	
Permeate blank b	*	
Challenge suspension	4.35 x 10^{10}	
Challenge test – after 5 minutes		
Feed a	1.56 x 10^6	
Feed b	1.55 x 10^6	
Permeate a	*	-
Permeate b	*	
Challenge test – after 10 minutes		
Feed a	1.50 x 10^6	
Feed b	1.87 x 10^6	
Permeate a	*	-
Permeate b	*	

Challenge test – after 15 minutes		
Feed a	1.50×10^6	
Feed b	1.51×10^6	
Permeate a	*	-
Permeate b	*	
Spike samples	Contact time 0 hr	Contact time 2 hr
Feed a	3.05×10^3	2.80×10^3
Feed b	2.70×10^3	3.40×10^3
Permeate a	6.85×10^3	3.20×10^3
Permeate b	3.90×10^3	*
Backwash	7.00×10^3	5×10^3

* Samples could not be counted because of heavy background growth.

Table 3. Challenge test with 0,5, 1 and 2 broken fibres per module

Sample description	*Bacillus* spores CFU/ l	MS2 phages PFU/ 10 ml
QA samples		
Permeate 1 blank	4	<1
Permeate 2 blank	2	<1
Permeate 3 blank	<1	<1
Feed blank	*	<1
Challenge suspension	5×10^9	1.8×10^{10}
Challenge test 5.5 m³/h		
5 minutes		
Feed	4.80×10^5	2.3×10^5
Permeate 1	60	5
Permeate 2	1	7
Permeate 3	45	2
10 minutes		
Feed	5.05×10^5	4.9×10^5
Permeate 1		7
Permeate 2	1	39
Permeate 3	40	17
15 minutes		
Feed	4.65×10^5	8.15×10^5
Permeate 1	87	9
Permeate 2	1	11
Permeate 3	43	40
Challenge test 10.5 m³/h		
5 minutes		
Feed	4.85×10^5	5.3×10^5
Permeate 1	60	18
Permeate 2	12	48
Permeate 3	19	59
10 minutes		
Feed	5.10×10^5	8.2×10^5
Permeate 1	71	57
Permeate 2	3	28
Permeate 3	39	25
15 minutes		

Feed	4.55×10^5	7.1×10^5
Permeate 1	48	36
Permeate 2	4	25
Permeate 3	40	16
Challenge test 14 m³/h		
5 minutes		
Feed	6.10×10^5	1.37×10^6
Permeate 1	92	168
Permeate 2	4	55
Permeate 3	71	77
10 minutes		
Feed	7.20×10^5	1.02×10^6
Permeate 1	90	130
Permeate 2	1	32
Permeate 3	62	142
15 minutes		
Feed	6.20×10^5	1.28×10^6
Permeate 1	95	115
Permeate 2	<1	112
Permeate 3	96	158

The membranes were challenged with $1.50 - 1.87 \times 10^6$ spores per litre. The blank samples and permeate samples of the challenge tests showed the presence of many bacteria that were able to grow on PCA at 37°C. Although *Bacillus* may have been part of this flora, this could not be determined, since the membrane filters used for this assay were covered with confluent growth of bacterial colonies. This heavy background was not observed in the previous experiment (Report 1), probably because the chlorination had reduced the background presence of aerobic bacteria in the installation to very low levels. The log-removal could therefore not be calculated.
The control samples that were spiked with the spores of the feed and permeate prior to the challenges and to the backwash sample after the chlorination/dechlorination after the challenge tests were finished showed that the spores were not inactivated.

3.2 Challenge test with broken fibres

The results of the challenge test with the broken fibres are given in Table 3.
As the *Bacillus* counts in the permeate were hindered by background bacteria in the challenge test with intact membrane elements, the samples for spore analysis were now pasteurised for 30 minutes at 60°C to suppress the background bacterial flora.
In contrast with the previous challenge tests (Report 1), the blank samples of the spores were not always negative. Both sample – pasteurisation and colony appearance indicated that the bacteria observed in the blanks were *Bacillus* spores. This indicates that the flushing and cleaning protocol had not removed all spores from the system.
The blanks for the phages were all negative, indicating that they had been adequately removed or inactivated by the cleaning protocol.

At all flows, both the spore and phage concentration in the feed was close to the concentration that could be calculated based on the concentration in the challenge suspension and the dilution of the challenge suspension in the feed water stream, indicating no significant losses of spores and phages during the challenge.
The adjustments of both feed water flow and challenge suspension flow lead to an increased concentration in feed water at 14 m³/h. The feed samples taken after 5, 10 and 15 minutes showed only a small degree of variation, indicating that the challenge suspension was homogeneous, as was the dosing of this suspension to the feed water in the subsequent experiments.

The log-removal was calculated for every individual flow and time combination (Tables 4 – 6 for MS2 phages and Tables 7-9 for *Bacillus* spores).

Table 4. Concentration of MS2 bacteriophages in the feed water

Feed				
0,5, 1 and 2 broken fibres per module				
	Filtration time			
Flow (m³/h)	5 min	10 min	15 min	Mean
5.5	230000	490000	815000	511667
10.5	530000	820000	710000	686667
14	1370000	1020000	1280000	1223333

Table 5. Concentration of MS2 bacteriophages in permeate with 0.5, 1and 2 broken fibres per module at different flow rates and filtration times

Permeate				
0,5 broken fibre per module				
	Filtration time			
Flow (m³/h)	5 min	10 min	15 min	Mean
5.5	5	7	9	7.0
10.5	18	57	36	37
14	168	130	115	138
1 broken fibre per module				
	Filtration time			
Flow (m³/h)	5 min	10 min	15 min	Mean
5.5	2	17	40	20
10.5	59	25	16	33
14	77	142	158	126
2 broken fibres per module				
	Filtration time			
Flow (m³/h)	5 min	10 min	15 min	Mean

5.5	7	39	11	19
10.5	48	28	25	33.7
14	55	32	112	66.3

Table 6. Calculated log-removal of MS2 bacteriophages with 0,5, 1 and 2 broken fibres at different flow rates and filtration times.

Log removal				
0,5 broken fibre per module				
	Filtration time			
Flow (m^3/h)	5 min	10 min	15 min	Mean
5.5	4.7	4.8	5.0	4.9
10.5	4.5	4.2	4.3	4.3
14	3.9	3.9	4.0	3.9
1 broken fibre per module				
	Filtration time			
Flow (m^3/h)	5 min	10 min	15 min	Mean
5.5	4.5	4.1	4.9	4.4
10.5	4.0	4.5	4.5	4.3
14	4.4	4.5	4.1	4.3
2 broken fibres per module				
	Filtration time			
Flow (m^3/h)	5 min	10 min	15 min	Mean
5.5	5.1	4.5	4.3	4.4
10.5	4.0	4.5	4.6	4.3
14	4.3	3.9	3.9	4.0

Table 7. Concentration of Bacillus spores in the feed water

Feed				
0,5, 1 and 2 broken fibres per module				
	filtration time			
Flow (m^3/h)	5 min	10 min	15 min	Mean
5.5	480000	505000	465000	483333
10.5	485000	510000	455000	483333
14	610000	720000	620000	650000

Table 8. Concentration of Bacillus spores in permeate with 0,5, 1 and 2 broken fibres per module at different flow rates and filtration times

Permeate				
0,5 broken fibre per module				
	filtration time			
Flow (m^3/h)	5 min	10 min	15 min	Mean

5.5	60		87	73.5
10.5	60	71	48	60
14	92	90	95	92

1 broken fibre per module

	filtration time			
Flow (m^3/h)	5 min	10 min	15 min	Mean
5.5	45	40	43	43
10.5	19	39	40	33
14	71	62	96	76

2 broken fibres per module

	filtration time			
Flow (m^3/h)	5 min	10 min	15 min	Mean
5.5	1	1	1	1
10.5	12	3	4	6.3
14	4	1	1	2.0

The highest removal of phages was observed with intact elements after 5 minutes of filtration. The removal decreased with increasing filtration time to 4.0 at 15 minutes.
In other studies with X-Flow UF membranes, complete removal has been observed. This indicates that in the configuration tested here either the modules or the connectors may have a very small leak rate. This has reduced the removal of the intact modules to 4.7 log.
The removal observed when 0,5, 1 and 2 fibres per module in the membrane installation were broken was slightly less than with the intact modules: 3.9 – 4.4 logs, except for the 0.5 broken fibres/module at the lowest flow rate. There was a tendency that increased flow rates increased breakthrough of MS2 phages. This is probably due to increased leak rates at increased TMP's.

As has been concluded in Report 1, the impaired integrity results in a significant reduction of the removal of *Bacillus* spores (Figure 2). The intact filters removed more than 6.9 logs of spores (data Report 1). At one broken fibre in 2 modules (0,5 broken fibre/module), the spore-removal was reduced to 4.0 logs. This is, however, still a very significant removal efficiency.
The overall average removal efficiency of the intact and impaired UF installation are given in table 10.

Table 9. Calculated log-removal of Bacillus spores with 0,5, 1 and 2 broken fibres per module at different flow rates and filtration times.

	Log removal			
0,5 broken fibres per module				
	Filtration time			
Flow (m^3/h)	5 min	10 min	15 min	mean

5.5	3.9		3.7	3.8
10.5	3.9	3.9	4.0	3.9
14	3.8	3.9	3.8	3.8
Mean	3.9	3.9	3.8	3.8

1 broken fibre per module

	Filtration time			
Flow (m^3/h)	5 min	10 min	15 min	Mean
5.5	4.0	4.1	4.0	4.1
10.5	4.4	4.1	4.1	4.2
14	3.9	4.1	3.8	3.9
Mean	4.1	4.1	4.0	4.1

2 broken fibres per module

	Filtration time			
Flow (m^3/h)	5 min	10 min	15 min	Mean
5.5	5.7	5.7	5.7	5.7
10.5	4.6	5.2	5.1	5.0
14	5.2	5.9	5.8	5.6
Mean	5.2	5.6	5.5	5.4

Table 10. Average log-removal of MS2 phages and Bacillus subtilis spores.

Condition	MS2 phages (log-removal)	Bacillus spores (log-removal)
Intact elements	4.7	> 6.9
0,5 fibres broken/module	3.9	3.8
1 fibre broken/module	4.0	4.1
2 fibres broken/module	4.3	5.4

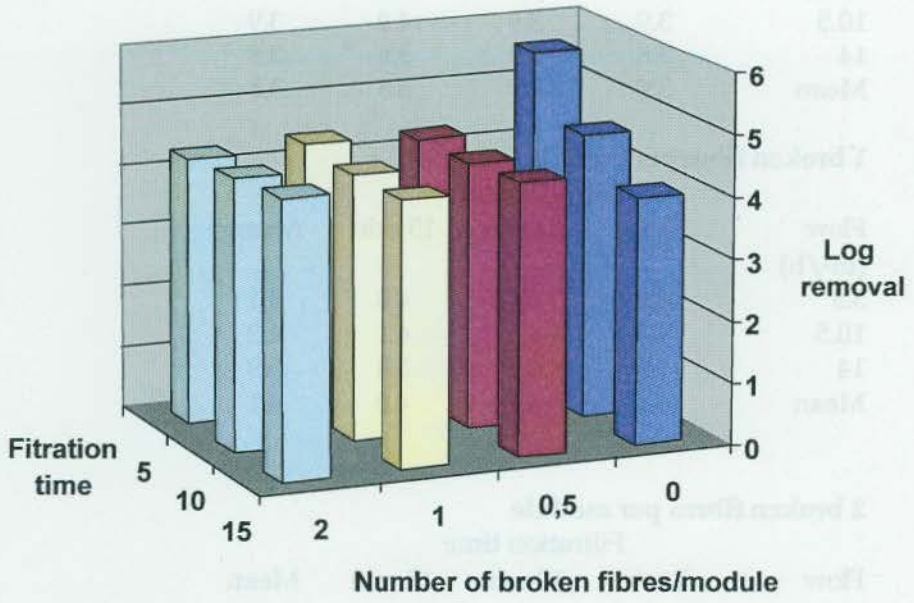


Figure 1. Removal of MS2 phages in X-Flow 0.8mm UFC M5 8 inch membranes with 0,5, 1 and 2 broken fibres per module at different filtration times.

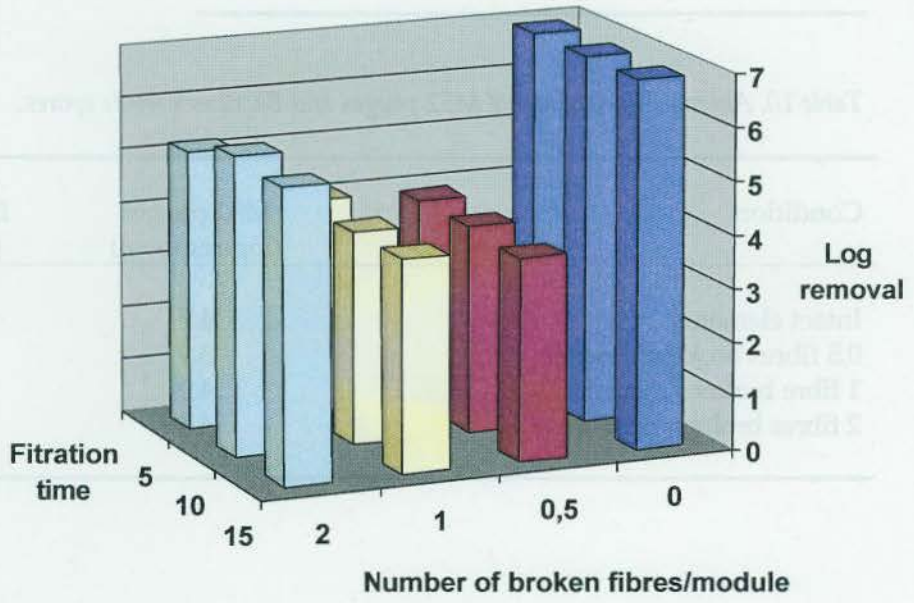


Figure 2. Removal of Bacillus spores in X-Flow 0.8mm UFC M5 8 inch membranes with 0,5, 1 and 2 broken fibres per module at different filtration times.

The installation with 2 broken fibres per module yielded a higher removal efficiency than with 0,5 or 1 broken fibre per module. This was most pronounced with the removal efficiency for spores, but was also seen with

MS2 (Table 10). We have checked and double-checked the sampling, sample codes and analysis. The probability that samples were switched or miscoded was considered negligible. As the difference was seen at all flow rates and for both phages and spores and the counts were clearly above the detection limit, this cannot be attributed to systematic or random errors in the microbial assays.
Another option could have been that the flow through the module with 2 broken fibres was much lower than through the other modules, but the hydraulics of the installation make a substantial difference in flow improbable (information X-Flow).

The conclusion from these challenge tests are that:

- Intact X-Flow UFC M5 0.8 mm modules in the installation tested remove >6.9 logs of *Bacillus* spores and 4.7 logs of MS2 bacteriophages.
- Impaired integrity of 0.5, 1 or 2 broken fibres per module reduces the removal: the minimum observed removal in this study was 3.8 logs for the *Bacillus* spores and 3.9 logs for MS2 phages.
- The effect of impaired intergity was most pronounced at the highest flow rates, probably because increased TMP's increased the leak rate.

I Testing protocol for challenge test X-Flow UF membranes

Revised 22/9/2000 and 29/9/00

Challenge test with intact membrane elements

Week 38

- Check availability of *Bacillus* spore suspension (10^{10}) and MS2 phage suspension (5×10^{12})
- Prepare and sterilise phage and Bacillus culture media and suspensions (minimally for 150 agar plates)
- Prepare minimally 25 sterilised sampling bottles of 1000 millilitres
- Prepare back-up sterilised thiosulphate solution according to NEN 6559
- X-Flow/NMT: preparation, cleaning and checking the membrane filtration unit. **The system should not contain any compounds in the water or membranes that may inactivate micro-organisms, such as free chlorine.**

Week 39, Monday

- Prepare 250 ml challenge suspension in sterilised drinking water, containing 3 ml phage stock (4.5×10^{12} MS2 phages) and 250 ml challenge suspension with Bacillus stock (10^{10} spores). Store at 4C.
- Prepare cooling boxes for cold storage and transport

Week 39 Tuesday

- Transport of challenge suspensions on ice and sampling and dosing materials to X-Flow, Hengelo
- Flush the membrane elements according to the X-Flow start-up procedure, **without the NaOCl step.**
- Mix the spore and phage challenge suspensions
- Start filtration at 10.5 m^3/h
- After 5 minutes: take four 1000 ml samples (1-4) of the feed and four 1000 ml samples (5-8) of the permeate. **Fill the 1 litre bottles completely, to be able to combine the spore and phage sample.** Store on ice.
- Connect the challenge suspension to the feed line
- Start dosing the challenge suspension at a rate of 1 l/h. Using a challenge of 15 minutes: 0.25 l with 9×10^{12} MS2 phages/litre are dosed into 2.6 m^3 of feed water, leading to an average feed concentration of approx 8.7×10^8/l, giving a limit of detection of maximally 5.9 logs.
- After 5 minutes: **first** collect 2 samples (9-10) of the permeate and **subsequently** collect 2 samples (11-12) of the feed. Store feed and permeate samples in separate cooling boxes to prevent cross-contamination.
- After 10 minutes, repeat this sampling regime (13-14; 15-16)
- After 15 minutes, repeat it again.(17-18; 19-20)

- Stop the challenge-dosing, keep the suspension for analysis
- Stop the filtration
- Backwash, chlorinate, dechlorinate and flush according to the X-Flow protocol
- Take a sample (21) of the backwash-water during the final flush. The backwash operates for only 60 seconds. During this backwash, one composite sample will be taken of the backwash water during these complete 60 seconds. Store on ice.

Week 39 Wednesday
- Receipt of samples at Kiwa
- Spike 2 blank permeate (3-4) and 2 blank feed (7-8) and the final backwash sample (21) with 100 ul of challenge suspension. Analyse directly and after 2 hours of incubation at room temperature.
- Analysis of the samples for Bacillus spores and F-specific RNA phages. Work from clean samples (permeates, blanks) via more contaminated samples (feed, spikes) to the heavily contaminated samples (challenge suspension, backwash water), according to the volumes/dilutions indicated in the table. **Analyse the remainder of the challenge suspension too.**

Sample	Expected MS2 concentration	Analyse in duplicate	Expected Bac. Spore concentration	Analyse in duplicate
Feed	9×10^5/ml	1 ml E5 E4 E3	2×10^4/ml	1 ml E3 E2 E1 E0
Permeate	0/ml	5 ml, 1 ml, 0.1 ml	0/ml	1000 ml
Blanks	0/ml	5 ml	0/ml	1000 ml
Challenge susp.	5×10^9/ml	1 ml E9 E8 E7 E6	10^9/ml	1 ml E9 E8 E7 E6
Backwash	Approx 8×10^6ml	1 ml E6 E5 E4 E3	10^6/ml	1 ml E5 E4 E3
Spikes	5×10^5/ml	1 ml E5 E4 E3	10^4/ml	1 ml E3 E2 E1 E0

Week 39 Thursday/Friday
- Counting spores or phages

Challenge tests with broken fibres

Week 39
- Preparation of sampling bottles and culture media as in week 38
- X-Flow/NMT: preparation and flushing of the membrane system

Week 40, Monday
- Prepare 1250 ml challenge suspension in sterilised drinking water, containing 3 ml phage stock (4.5×10^{12} MS2 phages) and 1250 ml challenge suspension with Bacillus stock (10^{10} spores). Store at 4C.
- Prepare cooling boxes for cold storage and transport

Week 40 Tuesday
- Transport of challenge suspensions on ice and sampling and dosing materials to X-Flow, Hengelo
- Flush the membrane elements according to the X-Flow start-up procedure, **without the NaOCl step.**
- Mix the spore and phage challenge suspensions
- Start filtration at 5.5 m^3/h
- Connect the challenge suspension to the feed line
- Start dosing the challenge suspension at a rate of 1 l/h. Using a challenge of 15 minutes: 0.25 l with 1.8×10^{12} MS2 phages/litre are dosed into 1.4 m^3 of feed water, leading to an average feed concentration of approx 3×10^8/l, giving a limit of detection of maximally 5.5 logs.
- After 5 minutes: **first** collect three samples of the permeate from the left, right and the mixture of left and right(samples 1-3) and **subsequently** collect a sample of the feed(sample 4). Store feed and permeate samples in separate cooling boxes to prevent cross-contamination.
- After 10 minutes, repeat this sampling regime(samples 5-8)
- After 15 minutes, repeat it again.(samples 9-12)
- Increase the feed to 10.5 m^3/h and the dosing to 2 l/h (feed conc: 3.4×10^8).
- Repeat same sampling regime at 5(samples 13-16), 10(samples 17-20) and 15 min(samples 21-24).
- Increase the feed to 14 m^3/h and the dosing to 4 l/h (feed conc.5×10^8)
- Repeat same sampling regime at 5(samples 25-28), 10(samples 29-32) and 15 min(samples 33-36).
- Stop the challenge-dosing, keep the suspension for analysis
- Stop the filtration
- Backwash, chlorinate, dechlorinate and flush according to the X-Flow protocol

Note: Three elements in series will be fitted in the pressure vessel. From left to right or vice versa the order of the elements and interconnectors should be the following: Element with 2 broken fibres- closed interconnector- element with no broken fibres-open interconnector- element with 1 broken fibre. This means in total 36 samples will have to be taken. All these samples will be analysed in duplo resulting in 72 data.

Week 40 Wednesday

- Receipt of samples at Kiwa
- Analysis of the samples for Bacillus spores and F-specific RNA phages. Work from clean samples (permeates, blanks) via more contaminated samples (feed, spikes) to the heavily contaminated samples (challenge suspension, backwash water), according to the volumes/dilutions indicated in the table.

Sample	Expected MS2 concentration	Analyse in duplicate	Expected Bac. Spore concentration	Analyse in duplicate
Feed	9×10^4/ml	1 ml E5 E4 E3	2×10^4/ml	1 ml E3 E2 E1 E0
Permeate	0/ml	5 ml, 1 ml, 0.1 ml	0/ml	1000 ml
Blanks	0/ml	5 ml	0/ml	1000 ml
Challenge susp.	10^9/ml	1 ml E9 E8 E7 E6	10^9/ml	1 ml E9 E8 E7 E6
Backwash	Approx 10^6ml	1 ml E6 E5 E4 E3	10^6/ml	1 ml E5 E4 E3
Spikes	10^5/ml	1 ml E5 E4 E3	10^4/ml	1 ml E3 E2 E1 E0

Week 40 Thursday/Friday

- Counting spores or phages

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Technical Bulletin

LT2ESWTR - LRV calculation through direct integrity testing

Document No.	TBU-GEN-INT-02-0633	*(replaces TBU-GEN-INT-02-0516)*

Related documents

Doc. No.	Originator	Description	Rev.	Date
1	Steve Algeier	EPA membrane Filtration Guidance Manual	815-D-03-008	june 2003
1	Steve Allgeier et.al	An Authoritative Review of LT2ESWTR: Guidance Manual for Membrane Filtration		March 2, 2003
2	James C. Vickers	Aspects of Hollow Fiber Membrane Integrity Testing for Regulatory Compliance and the Correlated Airflow Measurement (CAM) Test		July 2002
3	Frans Knops	LT2ESWTR Conformance of the Airflow Integrity Test		12 oct 2004

List of abbreviations

Abbreviation	Description
AIT	Airflow Integrity Test
ALCR	Air to Liquid Conversion Factor
CL	Control Limit
DIT	Direct Integrity Testing
lmh	Litre/m^2.h (membrane flux)
LRC	Log Removal Credit awarded
LRV	Log Removal Value
TMP	Trans Membrane Pressure
UCL	Upper Control Limit
UF	Ultrafiltration
VCF	Volumetric Concentration Factor

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Tables

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Equations

1 Introduction

This document derives the way to establish a log removal value (LRV) for a UF membrane system with X-Flow membranes. In order to establish this log removal a number of laboratory tests have been performed and data from full scale plants have been used.

Basis of this document is the "guidance manual for membrane filtration"[1] and "Aspects of Hollow Fiber Membrane Integrity testing for Regulatory Compliance"[2]. References to both documents can be found in the document reference list in the front.

It is Norit's philosophy to use worst case assumptions, when making calculations. This should be taken into account when comparing the results of the calculations herein with actual results from field tests.

The document e.g. calculates the number of broken fibers that generate a certain log removal (see chapter 10). This calculation is based on fibers breaking near the potting. If a fiber is broken exactly in the middle of the membrane module, the effect on the log removal is approximately 30 to 40% when compared to the effect of a fiber defect near the potting.

2 Theoretical background

The LRV is defined as being the following relation:

$$LRV_{DIT} = \log(\frac{Q_P}{VCF * Q_{breach}})$$

Equation 1: Log removal value

Where:

LRV_{DIT}	Log removal Value (Direct Integrity Testing)
Q_P	Filtrate flow from membrane unit to be tested
Q_{breach}	Flow of water through a breach of integrity
VCF	Volumetric concentration factor, for NORIT systems VCF = 1 (see document reference 3)

For the calculations, it is assumed that a defect occurs as a fully cut membrane fiber. Apart from fully cut fibers, the occurrence of fiber failure can also be associated with a pinhole or small crack. A fully cut fiber however simulates the worst case situation.

The flow of water through a defect consists of the sum of two streams, these streams being the individual streams through each section of fiber, as graphically represented below.

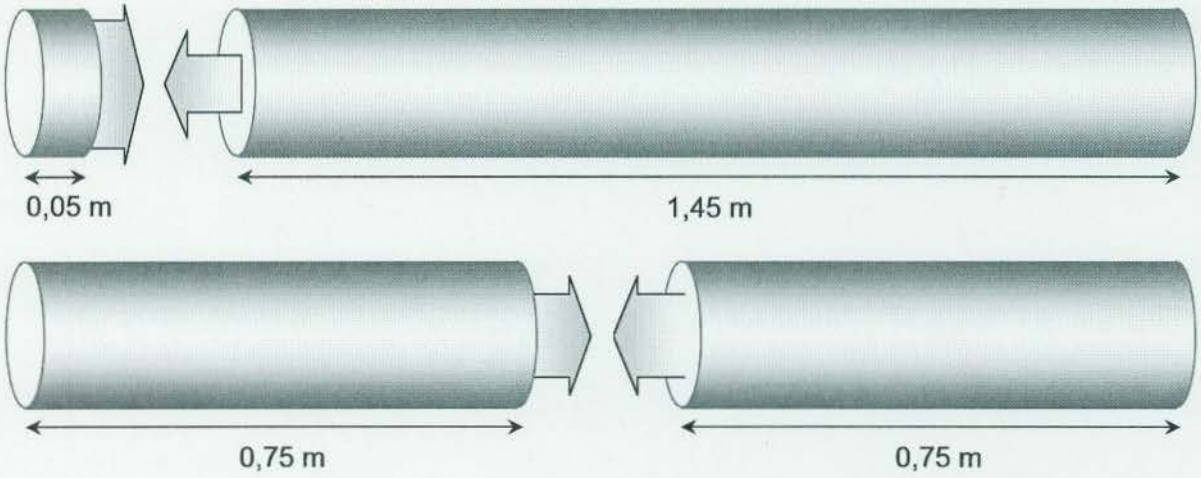

Figure 2.1: flow through broken fibers

Two cases have been displayed: the first one shows a fiber cut right after the epoxy potting (50 mm from the entrance of the membrane module), the second one shows a fiber cut in the middle of a fiber.

The arrows give a graphical representation of the water flows through the defect. Because of the shorter path length, the flow through a fiber section of 50 mm is higher than through a fiber section of 750 mm., assuming identical fiber failures. Similarly the flow through a fiber section of 750 mm is higher than the flow through a fiber section of 1450 mm.

The total defect flow is the sum of the flows through both sections of cut fiber. This document will detail two cases: the first one being the case with a fiber cut near the potting, the second one with a fiber cut in the middle of a fiber.

The water flow through the defect can not be measured directly on a full scale UF system. It is however possible to measure the air flow through a defect fiber. An empirical relation can be established between the water flow and the air flow:

$$Q_{air-defect} = ALCR * Q_{breach}$$

Equation 2: flow through defective fiber

Where:

$Q_{air-defect}$	*Airflow through a defect*
Q_{breach}	*Waterflow through a defect*
ALCR	*Air to Liquid Conversion Factor, as described in* [1]

3 Laboratory Testing

NORIT has tested single fibers at different lengths. Each time five fibers have been tested simultaneously. Multiple fibers have been tested in order to increase the accuracy of the laboratory testing. These fibers were pressurized with air and with water in two experiments. The air flow leaving the fibers was measured by collecting the air in an upside down calibrated cylindrical container in a large container of water. The water flow leaving the fibers was monitored by collecting the water in a calibrated cylindrical container).

In order to translate the results into an ALCR the following should be noted:

1. Pressures applied during water flow (filtration) and during air flow testing will differ from each other during operation of a plant. Pressure during water flow is equivalent to the actual trans membrane pressure during filtration. Pressure during air flow is the test pressure during the airflow testing.
2. The relationship between airflow and water flow will depend on the actual position of the fiber cut.
3. Only the air flow through the leak has been measured during the laboratory experiments. The diffusive airflow through the intact membrane pores has not been measured, since this depends on the actual measurement setup.

Airflow test pressure to be used has to be:[2]

1. Less than 80% of the bubble point pressure. The bubble point pressure of the XIGA UF membrane (0.025 µm pore size) is approximately 2,000 kPa = 20 bar.
2. Below the maximum differential pressure of the membrane. The maximum recommended differential pressure during filtration of the membrane is 2.5 bar.
3. Above the pressure required for detecting a defect of a given size. As stipulated by LT2ESWTR the minimum defect size to be identified is 3 µm. This corresponds to a bubble point pressure of 84.5 kPa = 0.845 bar. See document reference 3.

From above conditions it can be seen that air test pressure to be applied can vary between 0.845 bar and 2.5 bar. NORIT recommends to perform airflow testing at 1.0 bar. **1,0 bar air test pressure will be considered in what is to follow.**

The airflow through a fiber of 5 cm length and a fiber of 145 cm length constitute the total airflow through a fiber that is cut at the potting. The total airflow was 468 l/h @ 1 bar of air pressure. By comparison, the airflow through a fiber with a cut in the middle, i.e. two parts of 75 cm each, is only 254 l/h.

The same procedure was followed for the water flow. Here the tests were conducted at different pressures, to simulate a range of TMP's.

Water pressure [bar]	Waterflow (cut at potting) [l/h]	Waterflow (cut in middle) [l/h]
0.1	2.1	0.4
0.2	3.9	1.1
0.4	6.8	2.4
0.8	10.5	4.4
1.0	11.5	5.2
1.3	14.0	6.4

Table 3-1: water flow through defective fiber

The experiments show clearly that a fiber cut near the potting of a membrane element (50 & 1450 mm fiber) has a far worse effect than a cut in the middle of the fiber (750 & 750 mm fiber).

The worst case situation, a fiber cut near the potting, will be considered in the next paragraphs.

4 Air to Liquid Conversion Ratio (ALCR)

The ALCR has been calculated for 1 bar test air pressure, a fiber cut at the potting and is represented in the following figure:

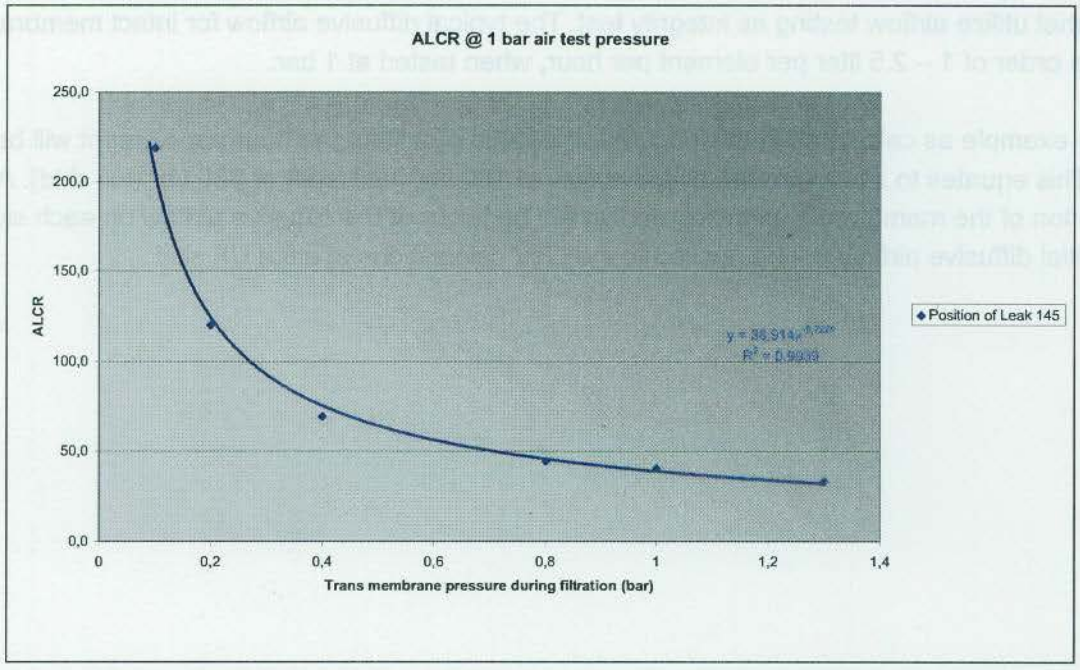

Figure 4.1: Air to Liquid Conversion Ratio versus TMP

In the graph, the ALCR has been fitted as follows:

$$ALCR = 38{,}914 * TMP^{-0{,}7224}$$

Equation 3: Empirical equation of ALCR versus TMP

5 Diffusive Air Flow

The diffusive air flow through an intact fiber can not be determined in small scale laboratory experiments. The diffusive airflow depends on the actual set up of the membrane units and the airflow testing equipment, is therefore site specific. NORIT does have access to several full scale plants that utilize airflow testing as integrity test. The typical diffusive airflow for intact membranes is in the order of 1 – 2.5 liter per element per hour, when tested at 1 bar.

For the example as calculated in this document, a value of 2 liters per hour per element will be used. This equates to a background diffusive flow of 160 l/hr (half skid) or 320 l/hr (full skid). After installation of the membranes an initial reading will be taken of the diffusive airflow on each skid. This initial diffusive airflow will be applied to the LRV calculations of each UF skid.

6 LRV calculation

The original formula for the log removal value is:

$$LRV_{DIT} = \log(\frac{Q_P}{VCF * Q_{breach}})$$

Equation 4: log removal value calculation

Assuming that:

- A fiber cut always appears near the potting (worst case scenario)
- The test pressure during the airflow test is 1,0 bar
- The volumetric concentration factor VCF is equal to 1.

The defect flow (water running though the defect) is calculated as follows:

$$ALCR = \frac{Q_{air}}{Q_{breach}}$$

Equation 5: correlation between air flow and water flow through a breached fibre

$$Q_{breach} = \frac{Q_{air}}{ALCR}$$

Equation 6: water flow through defective fiber

Where:

Q_{air} *Flow of air flow through the critical breach*

$$Q_{air-monitored} = Q_{air} + Q_{air-diffusive}$$

Equation 7: flow of air

$$Q_{air} = Q_{air-monitored} - Q_{air-diffusive}$$

Equation 8: flow of air

Where:

$Q_{air\text{-}monitored}$ *The actual air flow measured during the airflow testing @ 1 bar*

$Q_{air\text{-}diffusive}$ *Diffusive air flow through the membrane modules @ 1 bar*

With the above equations the water flow through the defective fiber(s) and the log removal can be calculated

$$Q_{breach} = \frac{Q_{air-monitored} - Q_{air-diffusive}}{38{,}914 * TMP^{-0{,}7224}}$$

Equation 9: water flow through defective fiber

$$LRV_{DIT} = \log \frac{Q_P * ALCR}{Q_{air} * VCF}$$

Equation 10: log removal value

Where:

ALCR *Air to Liquid Conversion Factor, see equation 3.*

VCF *Volumetric concentration factor (equal to 1 for dead end inside out membrane filtration)*

$$LRV_{DIT} = \log \frac{Q_P * 38{,}914 * TMP^{-0{,}7224}}{Q_{air-monitored} - Q_{air-diffusive}}$$

Equation 11: log removal value

Where:

Q_P Permeate flow during filtration [m^3/hr]

TMP Trans membrane pressure during filtration [bar]

$Q_{air\text{-}monitored}$ Displaced water flow during airflow testing [m^3/hr]

$Q_{air\text{-}diffusive}$ Diffusive air flow at 1 bar air test pressure [m^3/hr]

From this equation, it can be concluded that the LRV depends on:

- The amount of modules in a unit, in combination with the filtration flux;
- The TMP during filtration, and therefore the permeability of the membranes
- The diffusive airflow of an intact unit

7 Control Limits

A control limit (CL) is defined as a response that, if exceeded, indicates a potential problem with system and triggers a response. Multiple control limits can be set at different levels to indicate the severity of the problem.

The LT2ESWTR-mandated control limit is referred to as the upper control limit. This control limit is tied into the awarded log removal credit (LRC). The awarded LRC value for X-Flow XIGA S225 UFC M5 0.8 mm membranes is 4.

An additional alert control limit can be set at e.g. a log removal value of 4.3. This can be used as an alert value.

$$UCL = \frac{Q_P * ALCR}{10^{LRC} * VCF}$$

Equation 12: upper control limit

Where:

UCL	*upper control limit in terms of airflow through the integrity breach*
Q_P	*Permeate flow during filtration*
ALCR	*Air to Liquid Conversion Factor, see equation 3*
LRC	*Log removal credit awarded (4 log)*
VCF	*volumetric concentration factor (1)*

UCL is defined as the airflow through the critical breach. The actual UCL that is being monitored can be defined as follows:

$$UCL_{monitored} = UCL + Q_{Air-diffusive}$$

Equation 13: relationship between UCl and UCl monitored

By plugging in the correct factors for ALCR, VCF and LRC, this gives the following equation

$$UCL_{monitored} = \frac{Q_P * 38{,}914 * TMP^{-0{,}7224}}{10^4} + Q_{Air-diffusive}$$

Equation 14: upper control limit

Similarly to the upper control limit (alarm level) it is possible to define an alert level for the air flow testing.

$$CL = \frac{Q_P * ALCR}{10^{LRV} * VCF}$$

Equation 15: control limit

Where:

Q_P	*Permeate flow during filtration*
ALCR	*Air to Liquid Conversion Factor, see equation 3*
LRV	*Log removal value, alert level set at 4.3 log*
VCF	*volumetric concentration factor (1)*

$$CL_{monitored} = \frac{Q_P * 38{,}914 * TMP^{-0{,}7224}}{2{,}0 * 10^4} + Q_{Air-diffusive}$$

Equation 16: alert control limit

8 Case study (example)

To visualize the impact of an integrity breach (as measured by the airflow test), the LRV has been calculated as a function of the TMP during operation, assuming:

- 80 membrane modules tested simultaneously (this represents half a skid of 40 housings with 4 modules each)
- a diffusive airflow (intact system) of 160 l/h (this represents a base line airflow of 2 l/hr per module and is to be verified during commissioning)
- permeability ranging from 100-300 lmh/bar
- flux 100 lmh (this equates to a filtrate flow of 640 m^3/hr per skid or 320 m^3/hr per half skid
- transmembrane pressure 0.3 – 0.9 bar

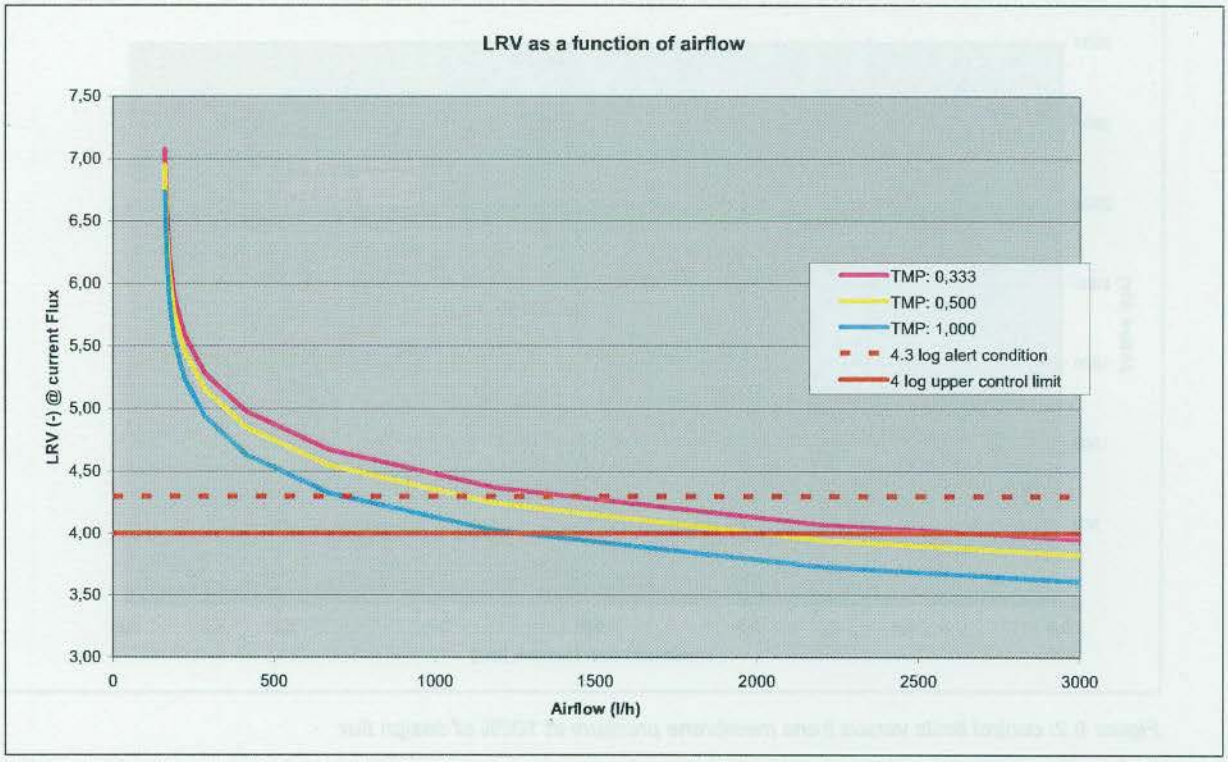

Figure 8.1: total airflow versus log removal

The equations in chapter 9 give the correct control limits for alert and for alarm:

$$UCL = \frac{320 * 38{,}914 * TMP^{-0{,}7224}}{10^4} + 0{,}160 = 1{,}245 * TMP^{-0{,}7224} + 0{,}16$$

Equation 17: upper control limit

$$CL = \frac{288 * 38{,}914 * TMP^{-0{,}7224}}{2{,}0 * 10^4} + 0{,}160 = 0{,}623 * TMP^{-0{,}7224} + 0{,}16$$

Equation 18: alert control limit

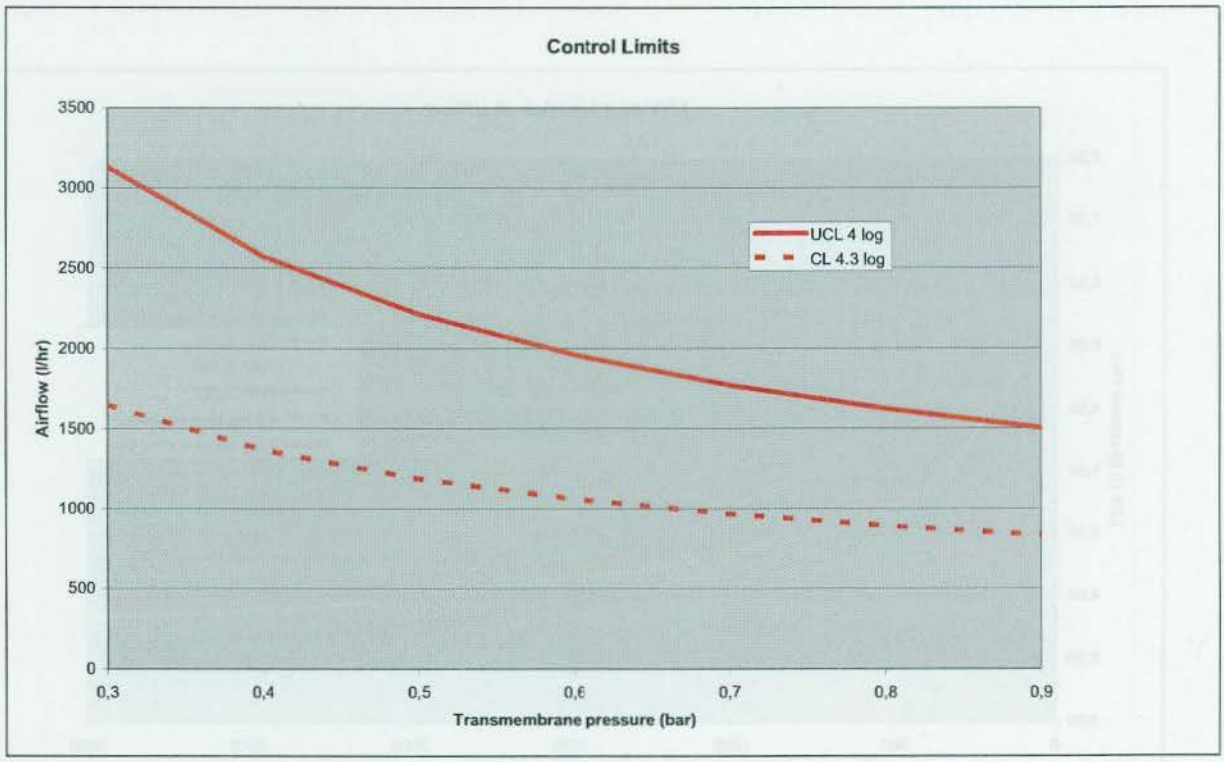

Figure 8.2: control limits versus trans membrane pressure at 100% of design flux

From the graph it can be seen that at different trans membrane pressures, the 4.3 log alert level and the 4 log alarm level are reached at different airflow rates.

At a trans membrane pressure of 0.3 bar (during filtration), the upper control limit for the monitored airflow is 3100 l/hr and the alert control limit is 1650 l/hr. This equates to 6 broken fibers (UCL) or 3 broken fibres (CL-alert).

At increasing trans membrane pressure this value decreases to 1500 l/hr (UCL) and 830 l/hr (CL-alert) for a trans membrane pressure of 0.9 bar (during filtration). This equates to almost 3 broken fibres (UCL) and 1.4 broken fibres (CL-alert).

Note: the above example describes an integrity test on half a UF rack (40 housings, only two membranes per housing being tested). The number of allowable broken fibres per full UF rack will be double the amount of allowable broken fibres per half rack.

If the flux deviates from the design flux (e.g. during periods of reduced output), this influences the control limits as well. The below graphs demonstrate the effect of varying trans membrane pressure and varying flow on the airflow rate to achieve various control limits. The LRV value is varied between 3.5 and 5 log in 0.5 log increments.

It should be noted that all graphs are based on a base line flow level (diffusive air flow) of 2 l/hr per membrane element.

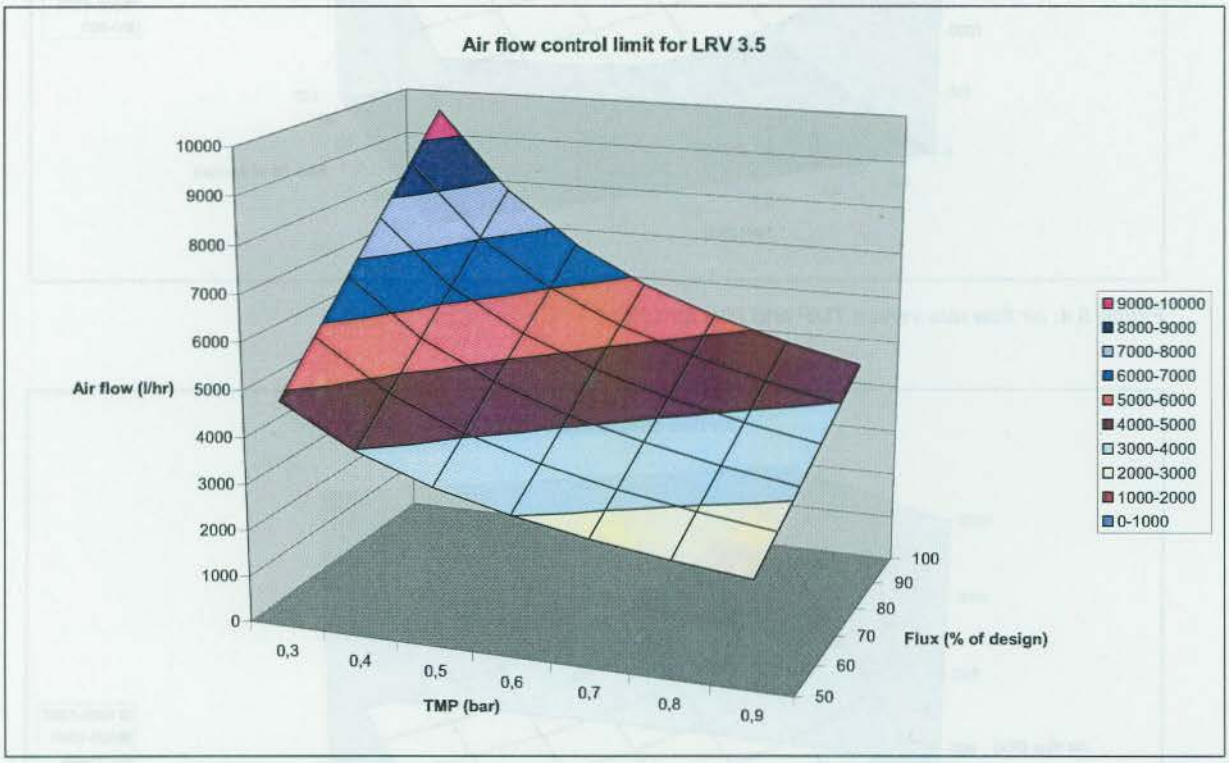

Figure 8.3: air flow rate versus TMP and Flux for LRC 3.5

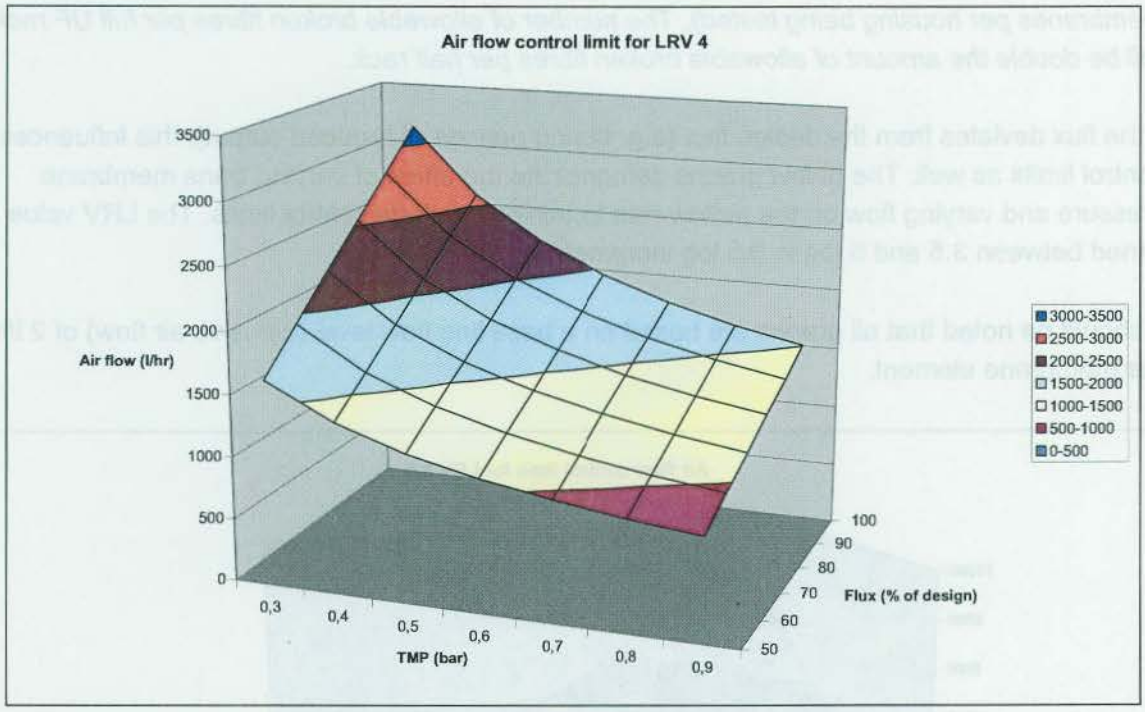

Figure 8.4: air flow rate versus TMP and Flux for LRC 4

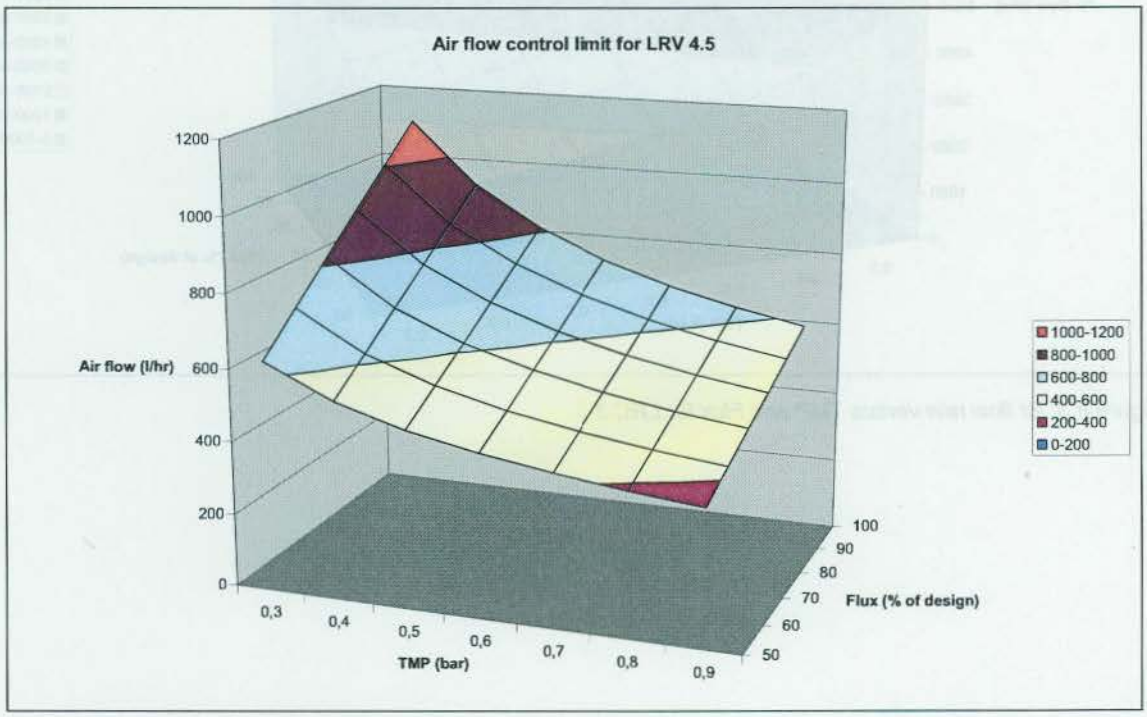

Figure 8.5: air flow rate versus TMP and Flux for LRC 4.5

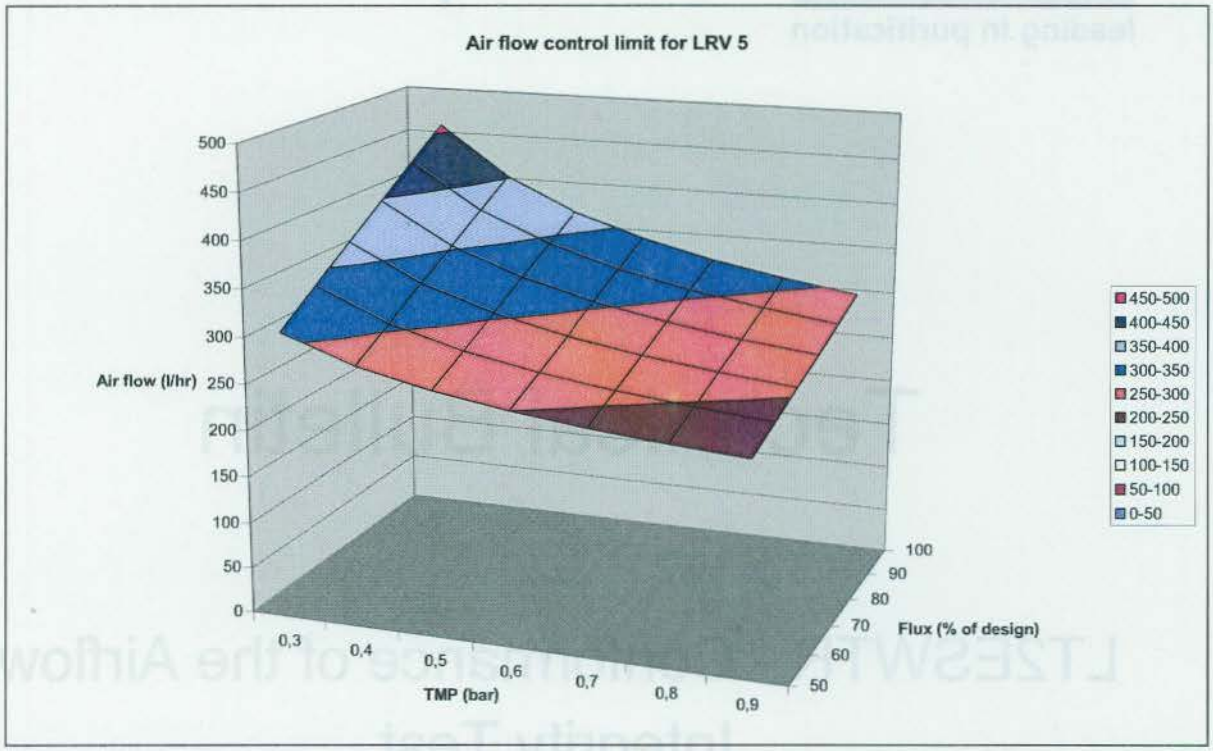

Figure 8.6: air flow rate versus TMP and Flux for LRC 5

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Technical Bulletin

LT2ESWTR - Conformance of the Airflow Integrity Test

Document No.	TBU-GEN-INT-03-0633	*(replaces TBU-GEN-INT-03-0526)*

List of abbreviations

Abbreviation	Description
AIT	Airflow Integrity Test
BP	Back Pressure
lmh	Litre/m^2.h (membrane flux)
TMP	Trans Membrane Pressure
UF	Ultrafiltration
VCF	Volumetric Concentration Factor

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Equations

1 Introduction

A simple, reliable and cost effective way of measuring the integrity of hydrophilic Ultrafiltration membranes is the airflow integrity test. The test relies on the fact that air below a certain pressure, which is called the bubble point pressure, can only pass an intact membrane by means of diffusion through the water filled membrane structure. When a fiber failure occurs, i.e. an opening bigger than the membrane pores is present in the membrane wall, air is allowed to pass the membrane by means of convective flow, on top the diffusive flow through the intact part of the membrane. This document addresses the LT2ESWTR requirement that for any direct integrity test a 3 µm defect should contribute to the response of the test. It also discusses the Concentration Factor (CF) defined within LT2ESWTR, which needs to be incorporated into the result of such a test.

1.1 Bubble point

For a given fluid, given membrane pore size and constant wetting, the pressure that is needed to force an air bubble through a pore is inversely proportional to the size of the pore. This relationship is given by Poiseulle's Law (or the Laplace equation):

$$P_{bubblepoint} = \frac{4K\sigma\cos\theta}{d} + BP_{max} \qquad (1)$$

Equation 1: Bubble point pressure

Where:

- K: Shape correction factor or tortuosity of the pore [-]
- σ: Surface tension [Nm^{-1}]
- θ: Liquid-solid contact angle [°]
- d Pore diameter [m]
- BP_{max} Maximum Backpressure on the system during the test

K is used to compensate for complex pore structures. For cylindrical pores K=1.

By applying equation 1, the minimum pressure required to generate convective flow can be calculated for any size pore or membrane imperfection. For the NORIT X-Flow membrane, the contact angle θ is 55 - 60°. A contact angle of 55 ° is considered a conservative value. Therefore this calculation uses a contact angle of 55°.

The maximum backpressure on the membrane is under worst case conditions (feed side fully drained, permeate side fully filled with water) the static height on the permeate side: 3.5 m = 35 kPa. During the course of the integrity test air will collect at the permeate side and the static height difference will decrease. Using a maximum backpressure of 35 kPa is a conservative assumption.

The Surface tension σ for water is a function of temperature. Perry's Chemical Engineering Handbook established the following relation between temperature and surface tension:

Temperature [K]	Temperature [°C]	Surface Tension [N/m]
273.15	0	0.0755
275	1.85	0.0753
280	6.85	0.0748
285	11.85	0.0743
290	16.85	0.0737
295	21.85	0.0727
300	26.85	0.0717

Table 1-1: surface tension versus temperature

Typically, the pore shape correction factor for a membrane is significantly less than 1, therefore using K=1 is a conservative assumption. Using Pore size and temperature as input variables, Equation 1 renders the following graph:

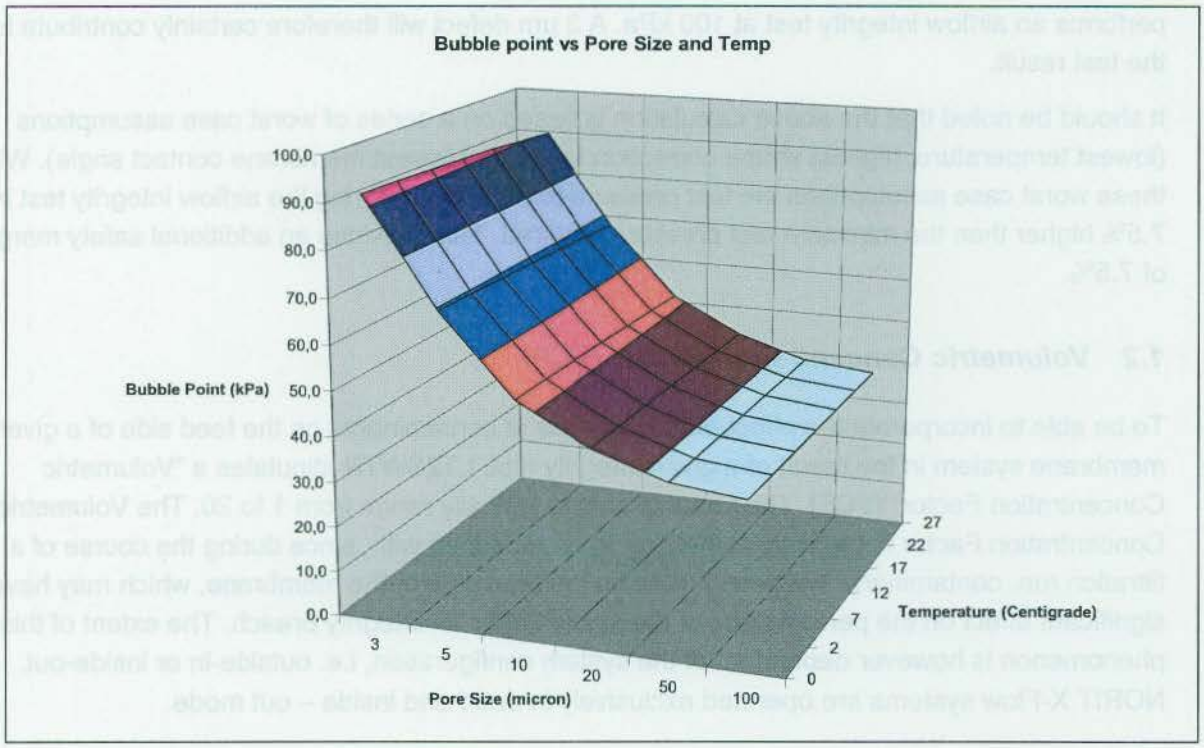


Figure 1-1: Bubble point pressure versus pore size and temperature

The lowest temperature yields the highest bubble point. As a worst case assumption a temperature of 0 Centrigrades is used. This gives the following relationship between pore size and bubble point pressure:

Pore size [µm]	$P_{bubblepoint}$ [kPa]
3	92.4
5	69.4
10	52.2
20	43.6
50	38.4
100	36.7

Table 1-2: bubble point pressure versus pore size at zero centrigrade

The table shows the minimum required pressure for generating convective flow through a 3 µm defect in the membrane is approximately 92.4 kPa. This means that a 3 µm defect will contribute to the response of a direct integrity test, as stipulated in the Long Term 2 Enhanced Surface Water Treatment Rule, provided the test pressure is higher than 92.4 kPa. NORIT typically

performs an airflow integrity test at 100 kPa. A 3 µm defect will therefore certainly contribute to the test result.

It should be noted that the above calculation is based on a series of worst case assumptions (lowest temperature, highest shape correction factor and lowest membrane contact angle). With these worst case assumptions the test pressure to be applied during the airflow integrity test is 7.5% higher than the minimum test pressure required. This provides an additional safety margin of 7.5%.

1.2 Volumetric Concentration Factor (VCF)

To be able to incorporate the effect of the increase of contaminants on the feed side of a given membrane system in the result of a given integrity test, LT2SWTR stipulates a "Volumetric Concentration Factor" (VCF). The factor is said to typically range from 1 to 20. The Volumetric Concentration Factor is certainly something to be reckoned with, since during the course of a filtration run, contaminants will accumulate on the feed side of the membrane, which may have a significant effect on the performance of the system after an integrity breach. The extent of this phenomenon is however dependant of the system configuration, i.e. outside-in or inside-out. NORIT X-Flow systems are operated exclusively in dead end inside – out mode.

1.2.1 Inside-out

For a "dead end inside-out" system, contaminants are collected and contained in the lumen of the fibers. There is no concentration increase on the feed side of a membrane module itself, other than on the inside of said fibers. If, for such a system, a single fiber's integrity is impaired, the contaminants in this one fiber will be forced through the defect, entering the permeate side. This will ONLY happen to the broken fiber, having no affect whatsoever on the remaining intact fibers. The contaminants retained within the other fibers cannot and will not be transported to this one defect. Therefore, a negligible amount (just the volume of this one fiber, which is 0,75 ml.) of contaminants will enter the permeate side, after which, the defect will pass feed water, with contaminants at the feed water concentration.

For an "inside-out" system, it can therefore be concluded that the volumetric concentration factor, as discussed in LT2SWTR is "1" at all time.

State of California—Health and Human Services Agency
Department of Health Services

California Department of Health Services

SANDRA SHEWRY
Director

ARNOLD SCHWARZENEGGER
Governor

March 14, 2006

Mr. Ingo Blume
Technology & Patents Officer
X-Flow B.V.
P.O. Box 739
7500 AS ENSCHEDE
The Netherlands

Dear Mr. Blume:

RESPONSE TO NOVEMBER 30, 2005 LETTER RE:NORIT X-FLOW SXL-225 MEMBRANE (COMMERCIAL DESIGNATION UFC M5LE)

Thank you for your letter in response to our November 4, 2005 conditional letter of acceptance. Based on the information provided, the Water Treatment Committee of the California Department of Health Services' Drinking Water Program agrees to conditionally accept the X-Flow SXL-225 membrane (commercial designation UFC M5LE) as an alternative filtration technology to meet the physical removal requirements of the current California Surface Water Treatment Rule (SWTR).

The X-Flow SXL-225 Membrane is accepted as an alternative SWTR filtration technology under California Code of Regulations, Title 22, Division 4, Environmental Health Chapter 17, Article 2, Section 64653(f) and can be used in the same housing as the previously accepted Norit X-Flow S225 UF membrane. The pathogen removal credits and conditions of operation (maximum flux and TMP) will remain the same.

Review and approval for the proposed design of any water treatment system proposing to use your technology will be handled on a case-by-case basis by the Drinking Water Program's individual District offices or local primacy agencies. Since the Drinking Water Program's District Engineers are responsible for evaluating the source water quality to be treated and issuing an operating permit, they will set the overall removal and inactivation requirements for a given installation. Design engineers proposing to use your alternative filtration technology should be aware that the minimum log removal requirements established by the SWTR are to be met using multiple treatment barriers. Your technology is recognized as being *one* component of this multiple barrier.

Approval for the use of your technology in any drinking water application is granted through the domestic water supply permitting process.

Also, please be aware that the WTC would prefer to see the "Rank and Percentile" plot in future reports, as opposed to the "probability output" from the regression analysis. Based on your examples, the "normal probability plot" used in your report is a regression or best fit of the data to a normal distribution and is not the preferred method for presenting the data. From what we can ascertain, from the limited documentation provided, the normal probability distribution places the log removal data at the percentile determined from the linear regression, *after* the data has been fit to a normal distribution. With a greater number of samples, the difference in the percentile associated with the last log removal data point, between the rank and percentile vs. regression analysis, would probably have been gone unnoticed.

In future correspondence it would be helpful if you would include the values, such as mean and median, that are being discussed. The regression statistics (correlation coefficient) are very low, which indicates the linear model is not a good fit. This would appear to contradict your argument for a linear or "normal" distribution. There are other statistical methods of evaluating normality, such as skewness and kurtosis.

Fortunately, neither of the preceding issues is critical to the conditional acceptance of your product because the log removal (at the 9th percentile) exceeds the maximum log removal credit (4.0) by 0.9 log. Rounding the performance from 4.9 to the nearest (lower) ½ log removal (4.5) or extrapolating the "rank and percentile" data distribution, by eye, to the 5th percentile, would still result in a log removal credit above the maximum allowed log removal credit (4.0). This may not always be the case and future product evaluations, should consider increasing the number of test runs (pathogen challenges) in order to avoid having your last data point be so close to the 5th percentile. The more immediate impact will be that this data set will not allow us to increase the log removal credit of your membrane without additional data.

Thank you for the opportunity to evaluate this new membrane. Should you have any questions regarding the content of this letter, please feel free to contact me at (510) 620-3499.

Very truly yours,

Richard H. Sakaji, PhD, PE
Senior Sanitary Engineer

cc: WT Committee
chron

Mr. Howard Johnson
North American Marketing Mgr.
1592 Bramblewood Dr.
Solon, IA 52333

Mr. John Minnery
MF/UF Product Mgr.
GE Ionics, Inc.
65 Grove St.
Watertown, MA 02472-2882

Projection info | Input parameters | Design parameters

Customer info

Customer	Michael	Proposal number	08-61-0
Project	1.1 MLD MBR Polishing	Design case	2 PRELIMINARY

Description

Assumptions UF feed water quality:
Ratio Turbidity : TSS = 1:1 & NTU = < 0.5 after pre-screening; pH = 7.8;
Temperature = 20°C; Total alkalinity = 100 mg/l CaCO3;
Total Fe < 0.1 mg/l; Total Mn < 0.1 mg/l; Ammonia < 2 mg/l after chloramination;
Phosphate < 1 mg/l; Oil & Grease < 0.5 mg/l; Total Organic Carbon (TOC) < 1 mg/l;
Biological Oxygen Demand (BOD) < 1 mg/l; Chemical Oxygen Demand (COD) < 1 mg/l

General comments to projection:
- UF feed water must be pre-screened with (automatic backwashable) strainer (< 200 µm).
- 100% safety margin on projected coagulant dosing pump capacity is required.
- 50% safety margin on projected CEB dosing pump capacities is required.
- CEB acid conc. based on reaching pH 2, subject to feed water quality (pH, alkalinity, etc...)
- CEB caustic conc. based on reaching pH 12, subject to feed water quality (pH, alkalinity, etc...)
- CEB chlorine conc. subject to feed water quality (TOC, ammonia, etc...)
- Coagulant conc. subject to feed water quality (TSS, TOC, etc...) and excludes precipitation of phosphate.

Design targets

Watersource	Surface water
Design based on	Feed supply
Units	Metric
Capacity	1.1 MLD

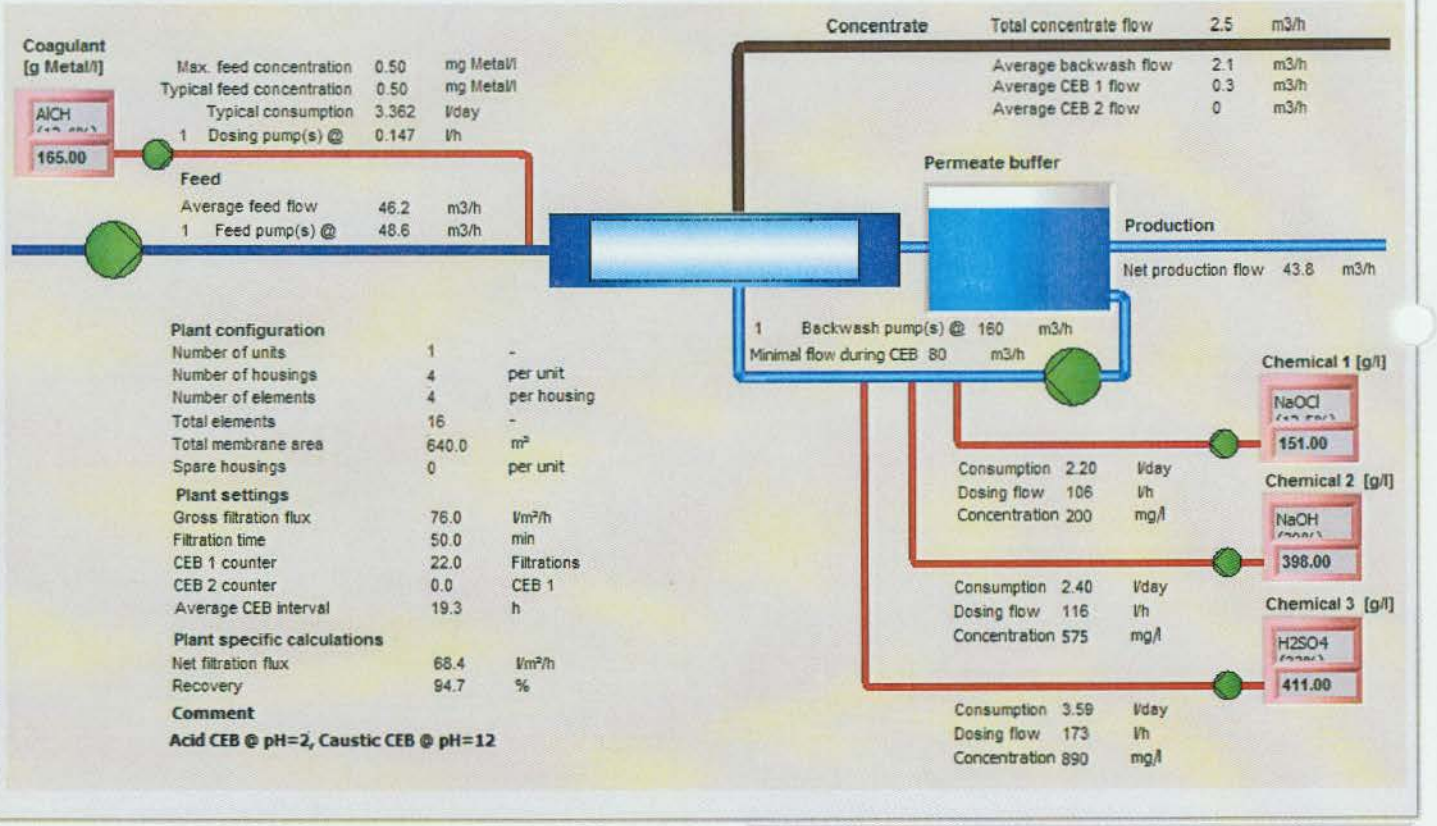
Water characteristics

Turbidity	0.5	NTU
Temperature	20	°C

Design info

Revision	1
Revision date	16/01/2009
Designed by	miller2
Approved by	

Projection info | Input parameters | Design parameters



Plant configuration

Number of units	1	-
Number of housings	4	per unit
Number of elements	4	per housing
Total elements	16	-
Total membrane area	640.0	m²
Spare housings	0	per unit

Plant settings

Gross filtration flux	76.0	l/m²/h
Filtration time	50.0	min
CEB 1 counter	22.0	Filtrations
CEB 2 counter	0.0	CEB 1
Average CEB interval	19.3	h

Plant specific calculations

Net filtration flux	68.4	l/m²/h
Recovery	94.7	%

Comment

Acid CEB @ pH=2, Caustic CEB @ pH=12

Program version	Version DBWS	Version DBSS
3.4	3.005	3.008

Norit X-Flow
leading in purification

Projection info | Input parameters | Design parameters

Plant specifications: Design

Membrane type: 0.8 mm (40 m²)

Description	User	Advise	Unit
Number of units	1	1	-
Housings	4	8	Unit
Elements	4	2	Housing
Total membrane area	640	640	m²
Total number of elements	16	16	-
Spare housings	0	0	Unit

Plant specifications: Calculations

Description	Advise	Unit
Average Filtration Flux	72.2	l/m²/h
Net Filtration Flux	68.4	l/m²/h
Recovery	94.7	%
Efficiency	90.0	%
CEB interval	19.3	h
Average Feed Flow	46.2	m3/h
Average Concentrate Flow	2.5	m3/h
Net Permeate Flow	43.8	m3/h
Overdesign	0.85	%

Process settings | CEB settings | Chemical stock

Primary settings

Description	User	Advise	Unit
Filtration Flux	76.0	95.0	l/m²/h
Filtration Duration	50.0	60.0	min
CEB 1 A	TRUE	TRUE	-
CEB 1 B	TRUE	TRUE	-
CEB 2 A	FALSE	FALSE	-
CEB 2 B	FALSE	FALSE	-
CEB 1 Counter	22	35	Filtr.
CEB 2 Counter	0	0	CEB1
Coagulant Dosing	TRUE	FALSE	-
Airflow Integrity Test	FALSE	FALSE	-

Backwash settings

Description	User	Advise	Unit
Backwash Flux	250	250	l/m²/h
Backwash Duration	35	35	sec
Dead time	35	35	sec
Ramp up/down time	8.0	8.0	sec
Start condition	85	85	% SV

Coagulant settings

Description	User	Advise	Unit
Max. concentration	0.50	0.00	mg/l
Typical concentration	0.50	0.00	mg/l
Chemical	AlCH	N.A.	-

Restrictions

Description	User	Advise	Unit
Max units / feed pump	1	1	-
Max units / BW pump	1	30	-
Max MH / Unit	40	40	-
Max elements / MH	4	4	-

Process settings | CEB settings | Chemical stock

Chemicals

Chemical	Conc. g/l
N.A.	0.00
Divos 2	1400.00
HCl	281.00
H2SO4 (33%)	411.00
HNO3	653.00
NaHSO3	453.00
NaOCl (12.5%)	151.00
NaOH (30%)	398.00
H2O2	396.00

Coagulants

Coagulant	Conc. g/l
N.A.	0.00
PACl	60.00
FeCl3	196.00
AlCH (12.4%)	165.00
Al2(SO4)3	38.00
N.A.	0.00
N.A.	0.00
N.A.	0.00
N.A.	0.00

Norit leading in purification

X-Flow

1.1 MLD MBR Polishing - 08-61-0

Designed by: miller2 Approved by: Printed by: miller2

Projection info | Input parameters | Design parameters

Plant specifications: Design

Membrane type: 0.8 mm (40 m²)

Description	User	Advise	Unit
Number of units	1	1	-
Housings	4	8	Unit
Elements	4	2	Housing
Total membrane area	640	640	m²
Total number of elements	16	16	-
Spare housings	0	0	Unit

Plant specifications: Calculations

Description	Advise	Unit
Average Filtration Flux	72.2	l/m²/h
Net Filtration Flux	68.4	l/m²/h
Recovery	94.7	%
Efficiency	90.0	%
CEB interval	19.3	h
Average Feed Flow	46.2	m3/h
Average Concentrate Flow	2.5	m3/h
Net Permeate Flow	43.8	m3/h
Overdesign	0.85	%

Process settings | CEB settings | Chemical stock

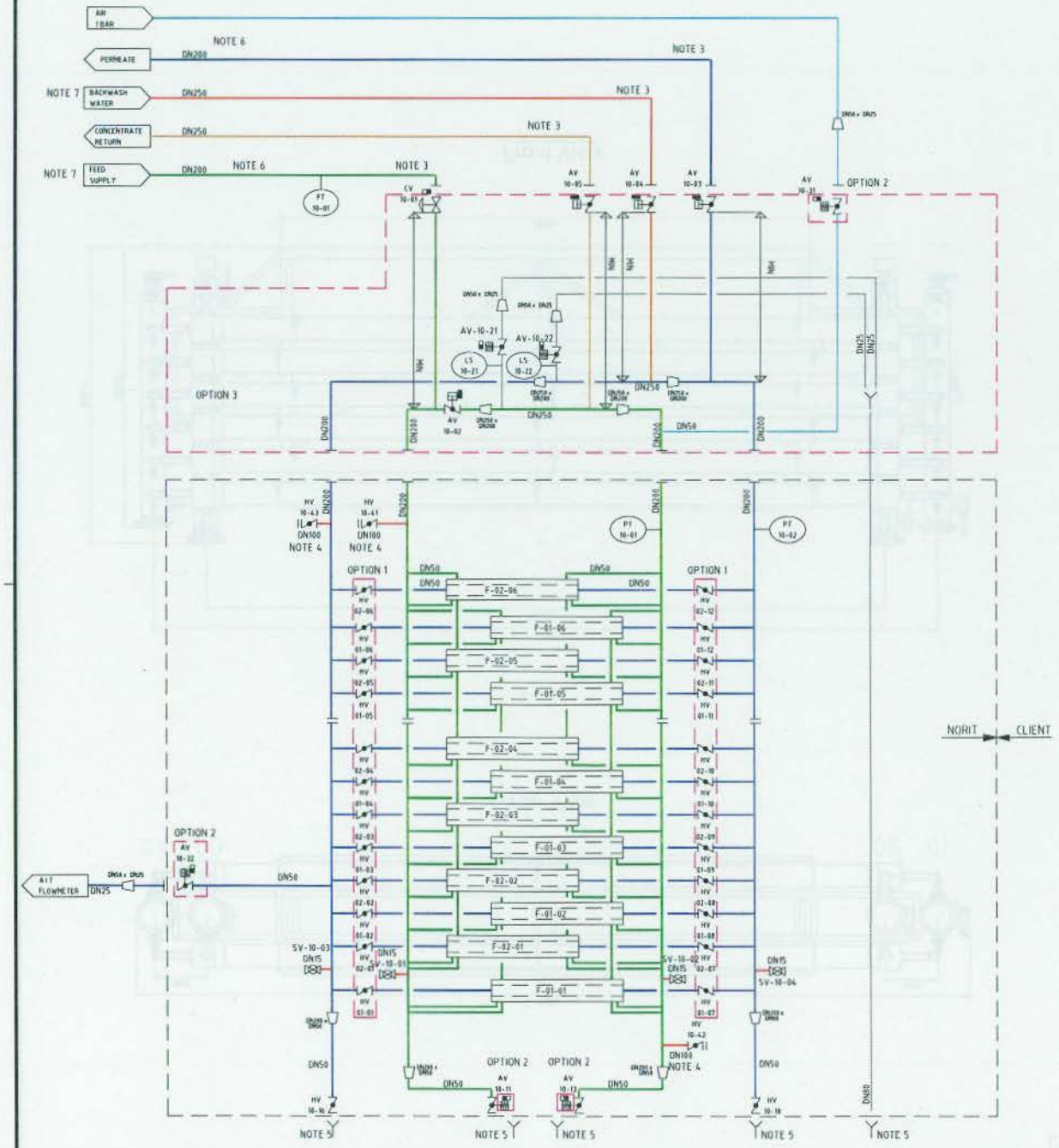
CEB 1 | CEB 2

	CEB A			CEB B		
	User	Advise	Unit	User	Advise	Unit
Dosing flux	125	125	l/m²/h	125	125	l/m²/h
Dosing duration	60	60	sec	60	60	sec
Post dosing flux	125	125	l/m²/h	125	125	l/m²/h
Post dosing duration	2	2	sec	2	2	sec
Soaking time	10	10	min	10	10	min
Chemical agent 1	NaOCl	NaOCl	-	H2SO4	HCl	-
Concentration agent 1	200.00	200.00	mg/l	890.00	450.00	mg/l
Chemical agent 2	NaOH	NaOH	-	N.A.	N.A.	-
Concentration agent 2	575.00	525.00	mg/l	0.00	0.00	N.A.
Rinsing flux	250	250	l/m²/h	250	250	l/m²/h
Rinsing duration	0	70	sec	70	70	sec
Dead time	90	90	sec	90	90	sec

Process settings | CEB settings | Chemical stock

CEB 1 | CEB 2

Dosing flux
Dosing duration
Post dosing flux
Post dosing duration
Soaking time
Chemical agent 1
Concentration agent 1
Chemical agent 2
Concentration agent 2
Rinsing flux
Rinsing duration
Dead time



WEIGHT:

EMPTY WEIGHT: xxxx KG
TOTAL WEIGHT INCL WATER AND MODULES: xxxx KG

OPTIONS:

1) - MEMBRANE HOUSING ISOLATION VALVES
2) - AIRFLOW INTEGRITY TEST, CONSISTING OF
  - AUTOMATIC AIR SUPPLY VALVE
  - AUTOMATIC AIT DISCHARGE VALVE
  - AUTOMATIC FEED DRAIN VALVES
3) - FEED, PERMEATE, BACKWASH AND CONCENTRATE TOP-MANIFOLDS

NOTES

1) - WATERHAMMER IS NOT ALLOWED IN THE UF UNIT
2) - SURGE / NEGATIVE PRESSURES DURING BOTH STATIC AND DYNAMIC UNIT OPERATION IS NOT ALLOWED
3) - NEED FOR MANUAL UF UNIT ISOLATION FACILITIES TO BE DETERMINED BY THE CLIENT
4) - CIP/FLUSH CONNECTION (NOT USED DURING NORMAL OPERATION)
5) - DRAIN PIPES TO BE FREE DRAINING
6) - FINAL LINESIZE DEPENDING ON MAX FEED FLOW
7) - CENTRAL FEED AND BW HEADER TO BE EQUIPPED WITH AUTOMATIC VENT VALVES AT HIGHEST POINT TO AVOID ANY RISK OF AIR INGRESS TO THE MEMBRANES

VALVES & INSTRUMENTS

CV-10-01 : FEED CONTROL
AV-10-02 : FEED BLOCK
AV-10-03 : PERMEATE
AV-10-04 : BACKWASH
AV-10-05 : CONCENTRATE
AV-10-11 : DRAIN FEED L
AV-10-13 : DRAIN FEED R
HV-10-16 : DRAIN PERMEATE L
HV-10-18 : DRAIN PERMEATE R
AV-10-21 : VENT FEED L
AV-10-22 : VENT FEED R
AV-10-23 : VENT PERMEATE L
AV-10-24 : VENT PERMEATE R
AV-10-31 : AIR SUPPLY
AV-10-32 : AIT DISCHARGE

HV-10-41 : CIP FEED L
HV-10-42 : CIP FEED R
HV-10-43 : CIP PERMEATE
SV-10-01 : SAMPLE FEED L
SV-10-02 : SAMPLE FEED R
SV-10-03 : SAMPLE PERMEATE L
SV-10-05 : SAMPLE PERMEATE R
PT-10-01 : PRESSURE TRANSMITTER FEED/CONC
PT-10-02 : PRESSURE TRANSMITTER PERM/BW
LS-10-21 : LEVEL SWITCH FEED L
LS-10-22 : LEVEL SWITCH FEED R
LS-10-23 : LEVEL SWITCH PERMEATE L
LS-10-24 : LEVEL SWITCH PERMEATE R

PIPING

1) - ALL PIPING MATERIAL IS BASED ON HDPE DIN 2501 PN10
2) - BATTERY LIMIT FLANGES XIGA LYNN SKIDS AND BOTTOM/TOP MANIFOLDS (OPTION 3) SHALL BE DIN 2501 PN16
3) - GUIDELINES FOR LINESIZING BOTTOM/TOP MANIFOLDS AND FEED, PERM, BW AND CONC LINES: MAX. 2 M/S FOR FEED/PERMEATE, MAX. 3 M/S FOR BACKWASH/CONCENTRATE

LINESIZE SPECIFICATIONS

DN	D out (mm)	E (mm)	D in (mm)
15	20	1,9	16,2
20	25	2,3	20,4
25	32	2,9	26,2
32	40	3,7	32,6
40	50	4,6	40,8
50	63	5,8	51,4
65	75	6,8	61,4
80	90	8,2	73,6
100	110	10	90
125	140	12,7	114,6
150	180	16,4	147,2
200	225	20,5	184
250	280	25,4	229,2
300	315	28,6	257,8
350	355	32,2	290,6
400	400	36,3	327,4
450	450	40,9	368,2
500	500	45,4	409,2

FOR INFORMATION ONLY

Norit X-Flow
loading in purification
X-Flow BV
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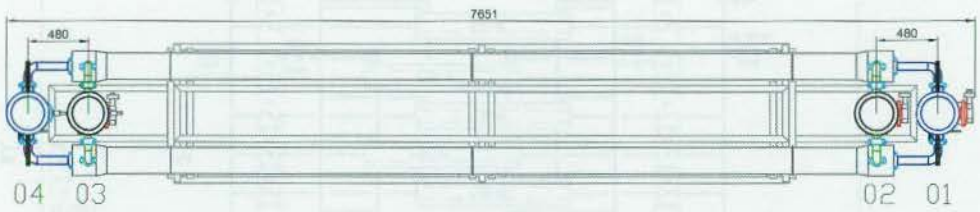
E info@xflow.nl · I www.xflow.nl

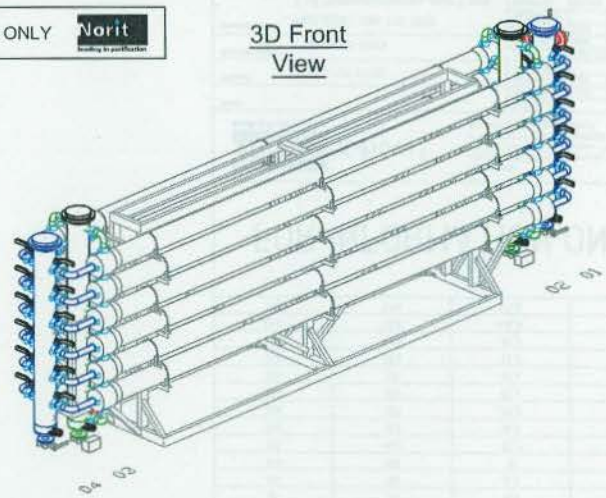
Client:	-	Date first issue	11-04-2007
Project:	XIGA TYPE LYNN	Drawn by	ABM
		Checked by	HLE
		Approved by	
Drawing number:	LYNN-206T-2000	Status	FOR INFORMATION ONLY
		Date latest revision	11-09-2008
Drawing name:	P&ID XIGA LYNN TOP FEED	Revised by	MWI
	2 x 6 Membranehousings, each 4 mod	Approved by	
		Projection	Original drawing size: A1

Scale: -
Sheet: 01 OF 01
Revision: D-06
Signature:

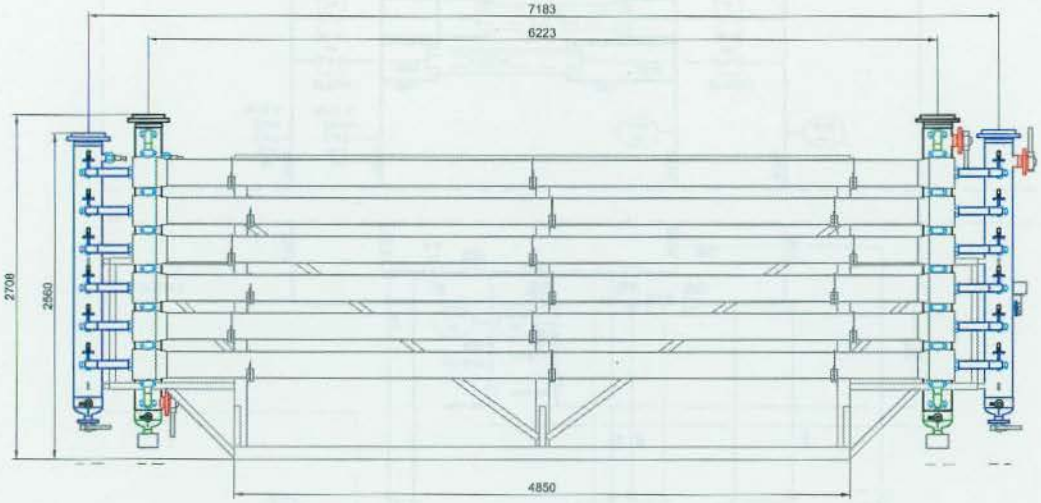
FOR INFORMATION ONLY Norit



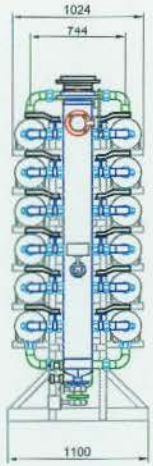
Top View



3D Front View



Front View



Side View

NOTES :

FLOWS :

- FEED	Min Flow : 77	(note1)	Max Flow : 240	(note3)
- FEED (filling)	Min Flow : 40		Max Flow : 50	
- PERMEATE	Min Flow : 77	(note1)	Max Flow : 240	
- BACKWASH	Min Flow : 240	(note2)	Max Flow : 480	
- CONCENTRATE	Min Flow : 240	(note2)	Max Flow : 480	

NOTE 1): based on min advised flux of 40 l/m/h
NOTE 2): during chemical enhanced backwash
NOTE 3): based on drinking water quality feed water

PRESSURES :
- Max pressure in installation : 3 Bar(g)
- Max pressure airflow inlet : 1 Bar(g)
- Max pressure air on field panel : 8 Bar(g)

CONNECTIONS :
- drain connections must be connected with Victaulic couplings and open drainage is preferred.
- supporting framework for central Feed, Backwash, Permeate and Concentrate top manifold by Client. Norit UF Skid will not take the load !
- connections to Norit UF skid must be without tension or stress !

WATERHAMMER :
- Waterhammer is not allowed in the UF-skid.

SURGE :
- Surge / negative pressures during both static and dynamic skid operation is not allowed.

TEMPERATURE :
- Min Ambient Temp : 2 °C , Max Ambient Temp : 40 °C
- Min Feed water Temp : 2 °C , Max Feed water Temp : 40 °C
- Min Backwash water Temp : 2 °C , Max Backwash water Temp : 40 °C

AIR QUALITY :
- Air quality for airflow integrety test to be at least ISO 8573-1, class 1/3/1 (oil / water/ particles).
- Air to local field panel must be at least ISO 8573-1, Class 2 / 3 / 2. (Oil, water, particles)

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Client :		Date first issue	01-10-2007
		Drawn by MVI	Scale 1 : 20
Project :		Checked by	Sheet 01 OF 01
		Approved by	
Drawing number : XIGA-LYNN-206T-2200		Status	Information Only
		Date latest revision	21-12-2007
Drawing name : Layout XIGA LYNN 2 x 6 x 4 elements, Top manifolds		Revised by MVI	Revision D-02
		Approved by HLE	Signature
		Projection	Original drawing size A1

Ultraviolet Disinfection System Validation Report

Final Report

27th September 2008

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Designed for printing double-sided.

Document Information

Status	Version	Prepared By	Issued To	#	Date	Reviewed	Approved
Progress Report	Version 1	D Deere	Shaun Cumming	pdf	29/7/07	N/A	
Working Draft	Version 2	D Deere	Shaun Cumming	pdf	27/11/07	N/A	
Completed First Draft	Version 3	D Deere and Martin Krogh	Shaun Cumming and DHS Victoria	pdf	21/1/08	Yes	Changes suggested
Updated Draft Report	Version 4	D Deere	Shaun Cumming	pdf	28/1/08	Yes	Additions suggested
Updated Draft Report	Version 5	D Deere	Shaun Cumming	pdf	9/2/08	Yes	Additions suggested
Updated Draft Report	Version 6	D Deere	Shaun Cumming	pdf	12/2/08	Yes	Additions suggested
Final Draft Report	Version 7	D Deere	Georgie O'Dwyer	pdf	4th August 2008	Yes	Additions suggested
Final Report	Version 8	D Deere	Georgie O'Dwyer	pdf	27th September 2008		

Created By: **Water Futures Pty Ltd**

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Citation: Deere, D. (2008) Orica Ultraviolet Disinfection System Validation Report. Report produced for Orica by Water Futures Pty Ltd.

File Name: Validation Report V8.doc

Client: Georgie O'Dwyer

Name of Organisation: Orica

Name of Project: Ultraviolet Disinfection System Validation

Name of Document: Independent Validation Report

Document Version: Version 8

Contents

Figures

Tables

1. Executive Summary

- Commercially produced modular low pressure high output (LPHO) ultraviolet (UV) disinfection reactors were validated to establish the reduction equivalent dose (RED) for a range of water flow rates and water UV transmissivity (UVT) levels.
- A key design feature of the reactors is that lamps are not directly contacted by the water which reduces fouling and simplifies maintenance. To achieve this, reactors allow water to pass through a flow tube surrounded by UV lamps.
- The reactors are modular - once one flow tube has been validated it is possible to arrange multiple flow tubes in series and in parallel to allow scale up against the validated reactor performance.
- Two contemporary guideline documents were considered in undertaking the validation:
  - United States Environmental Protection Agency Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule (2006) (the UVDGM method). The UVDGM is aimed at high UVT drinking water for regulated US water supplies.
  - National Water Research Institute and American Water Works Association Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, Second Edition (2003) (the NWRI method). The NWRI document is aimed at potable water and reuse applications.
- Two different sizes of reactor were validated:
  - 89 mm diameter flow tube; and
  - 60 mm diameter tube.
- Three flow rates were used for each reactor to cover the desired validated range:
  - Approximately 2, 4 and 8 L/s for the 89 mm reactor; and
  - Approximately 1, 2 and 4 L/s for the 60 mm reactor
- Two different water types were used to cover the range of applications anticipated:
  - Municipal wastewater conventionally treated by activated sludge and clarification; and
  - Municipal tap water conventionally treated by coag-floc-sed-filtration and chlorination.
- For each water type, three UVT levels were considered to cover the desired validated range:
  - Approximately 60, 80 and 90% for potable water; and
  - Approximately 40, 50 and 60% for wastewater.
- Two different reactor arrangements were validated to cover scale-up arrangements:
  - One-stage reactor consisting of one flow tube; and
  - Two-stage reactor consisting of two flow tubes in series.
- Collimated beam testing (CBT) was undertaken to establish the UV dose-response relationship for a sub-sample from a preparation of MS2 FRNA bacteriophage (MS2) in water and wastewater.
- Biodosimetry was performed using a second sub-sample of the same MS2 preparation whereby the difference between the concentrations of MS2 in the influent water entering, and effluent water leaving, the reactors was used to calculate the reduction equivalent dose (RED) using the dose-response relationship derived in the CBT testing.
- Equations and nomograms (look-up plots) were developed that allow the calculation of the RED that has been demonstrated for each reactor within the tested range of flow rates and UVT.
- This report summarises the studies and presents specific RED values and pathogen inactivation credits for particular reactor design and describes how to use equations and nomograms on a case-by-case basis for specific reactor applications in their regulatory contexts.

2. Introduction

2.1. UV disinfection system validation

UV disinfection is rapidly increasing in its popularity for potable water and recycled water disinfection. Key features of UV disinfection are its ability to readily inactivate protozoan pathogens that are resistant to chlorine and chloramine, as well as the avoidance of disinfection by-product formation which is an issue with oxidant disinfectants.

One complication of UV reactors is that the disinfection dose cannot be measured simply in the way that, for instance, chlorine is assayed on-line after a defined contact time. Therefore, a range of guidance documents have been developed to help set out methods for validating UV reactors. The validation process involves using microbial challenge testing to establish the dose of the UV reactor, and then operating the UV reactor within the conditions proven during the challenge testing.

2.2. Overview of methodology

This report presents the key results arising from a challenge test performed during September 2007 on a commercially available UV reactor design. The reactor had been validated previously (during 2003 and 2004) but since that time, new guidelines and industry practices have necessitated an updated validation. For example, UV intensity sensors were not installed during the previous validation and these are required for conformity with some guidance documents.

To provide a validation to meet regulatory requirements in US high UV transmissivitiy (UVT) potable water applications, the United States Environmental Protection Agency Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule (2006) (the UVDGM method) was used.

The UVDGM document formed the dominant guidance manual adopted in this validation, defining considerations such as validation design, interpretation and quality assurance and quality control criteria. The UVDGM is specifically tailored to high UVT drinking water supply applications.

To provide a validation for low UVT applications, particularly in relation to wastewater, the National Water Research Institute and American Water Works Association Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, Second Edition (2003) (the NWRI method) was also used.

The NWRI and UVDGM are not mutually exclusive and have much in common. Both methods employ collimated beam testing (CBT) to establish does-response relationships between UV dose and challenge microorganism inactivation. Both methods then use biodosimetry whereby the challenge microorganism, once characterised by the CBT, is dosed into the reactor. The challenge microorganism is then assayed on both the influent and effluent to establish the degree of inactivation and, thereby, the reduction equivalent dose (RED) achieved. The methods differ in how the statistical analysis of the data is undertaken.

2.3. Validation program participants

The Australian Water Quality Centre (AWQC) is wholly owned by the South Australian Water Corporation which is in turned wholly owned by the State Government of South Australia. The AWQC, based in Adelaide, is uniquely experienced within Australia in CBT and biodosimetry. The AWQC undertook the microbial aspects of the validation, as well as advising on engineering and general water quality aspects. The AWQC staff involved were PhD qualified, experienced water microbiologists with the work being undertaken in Australia's premier water research laboratory facilities.

Orica Watercare is a major supplier of water treatment chemicals and specialist water treatment systems worldwide. Orica is working in partnership with Enaqua and UVTA to supply customers with a novel non-contact UV disinfection system. Orica worked with these partners to manufacture a test rig which was supplied to the test site in Adelaide where the validation studies were performed.

Water Futures Pty Ltd is a specialist water science and engineering consultancy, independent of any other parties involved. The specialists involved in this work included a PhD water microbiologist, a chemical engineer with PhD in water chemistry and a masters-qualified accredited statistician. Water Futures Pty Ltd provided independent 'third party oversight' (as recommended under UVDGM at section 5.2.3, page 5-6). Water Futures Pty Ltd provided independent oversight of the design and independent review and analysis of the data obtained. This document represents that independent validation report.

2.4. Key features of the validation program

The approach adopted in undertaking this validation was conservative in several respects. Therefore, any conclusions drawn from the data presented in this report will be highly conservative and reliable in terms of public health protection. Examples of key features of conservatism in the assessment include the following:

- The statistical methods adopted by the NWRI and UVDGM are both conservative by design, introducing a range of safety factors in the RED values predicted upon analysing the data. The methods use lower bound confidence estimates for all statistics to ensure that the estimated RED values provided for any given reactor design are conservative.
- Aged lamps, at around 8,000 hours, were used throughout the experiments, representing the low end of the range of UV doses that the reactors would achieve under the test conditions.
- In full-scale reactors, flow tubes would either be surrounded by reflective stainless steel walls, or by additional lamps illuminating adjacent flow tubes. However, in the test rig, the flow tubes were surrounded by blackened walls (Figure 2-1).
- The assumptions about pathogen log inactivation credits use worst-case pathogens to assign those credits. For instance, inactivation rates estimated for viruses were based on highly resistant adenoviruses. This means that the actual log inactivation rates for other types of virus would be greater than the conservative default values.

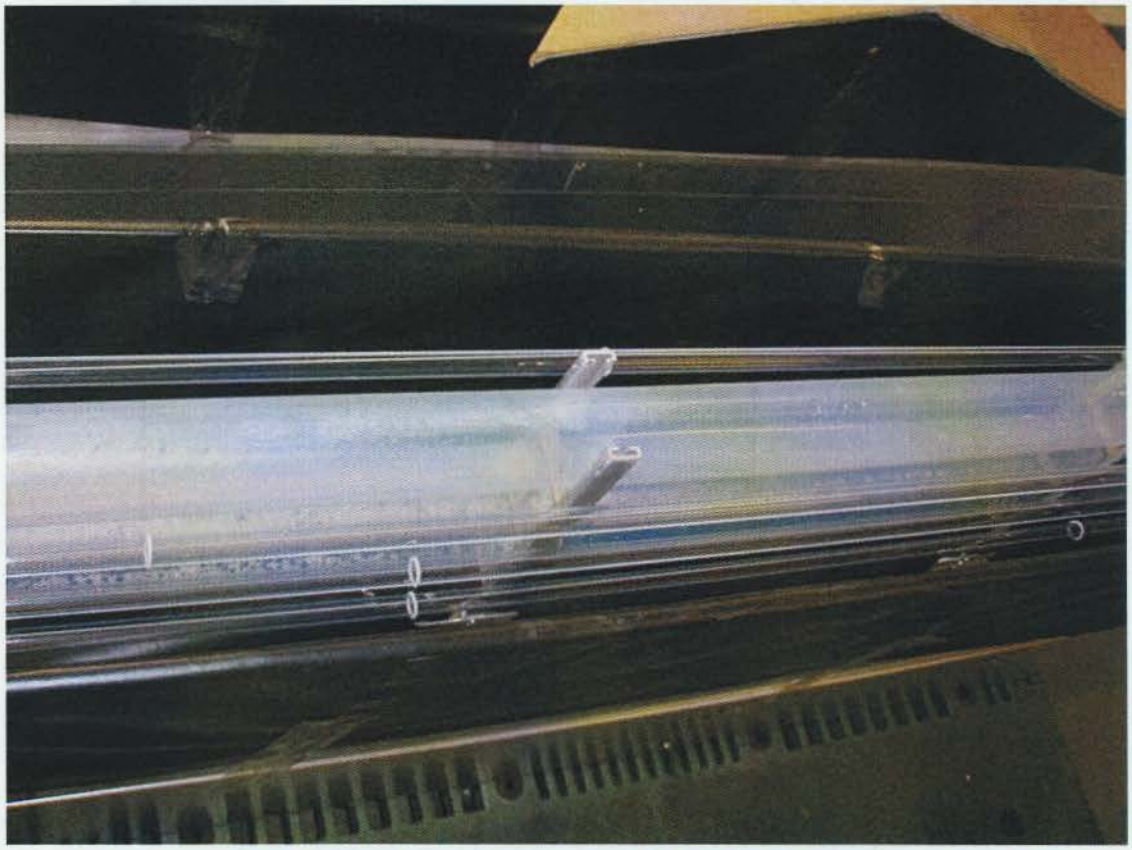


Figure 2-1. Close up of UV reactor test rig illustrating the black plastic on the internal surfaces.

2.5. Overview of Validation Approach

The validation approach involved three steps (Figure 2-2):

1. Part A: Establishing the UV sensitivity of a challenge microorganism in a collimated beam testing (CBT) apparatus. Part B: At the same time, dosing UV reactors with the challenge microorganism and measuring the influent and effluent concentrations.
2. Calculating the UV dose applied to the challenge microorganism in the UV reactors using the UV dose sensitivity of the challenge microorganism and the degree of inactivation measured in the UV reactors. This gives the reduction equivalent dose (RED) for the challenge microorganism.
3. Adjust for uncertainties to convert the RED into pathogen inactivation estimates.

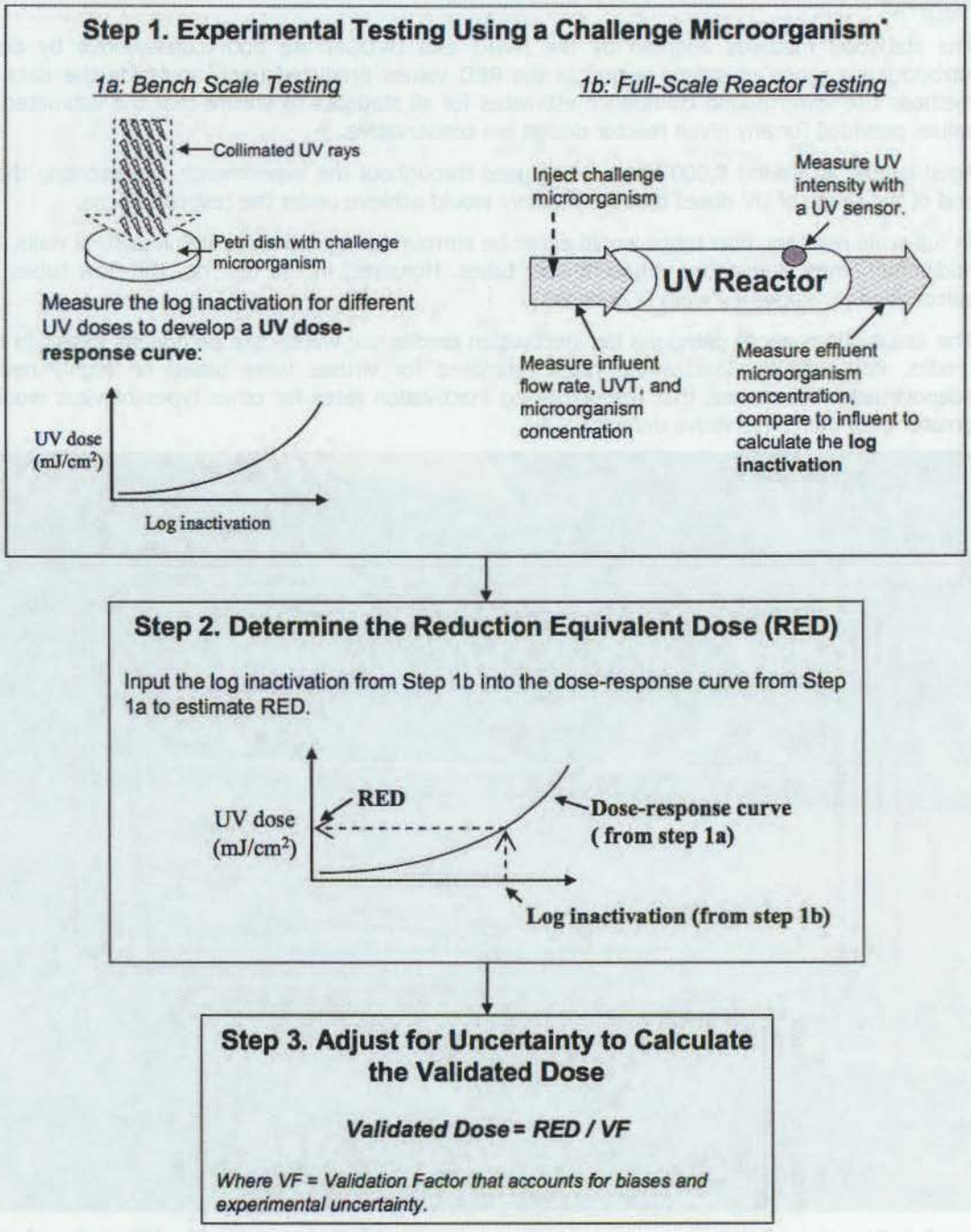


Figure 2-2. Extract from the UVDGM (Figure 5.1, page 5-4)

3. Test rig specifications

3.1. General details

General information on the validation undertaken in given in Table 3-1 based on information provided by Enaqua, Orica and Australian Water Quality Centre.

The test rig involved three flow tubes in parallel being held in two rigs in series. A 60 mm and 89 mm rig were both assembled. A feed tank was used to supply water via pumps into the rig. Illustrated in Figure 3-2 and Figure 3-3 are illustrations of the test rig as used.

Table 3-1. General information.

Item	Details
Type	Off site validation in test rig
Location	UVTA warehouse, Lewis Road, Glynde, Adelaide, South Australia, Australia
Period	September 2007
Reactor type	AFP™ 840 non-contact UV reactor
Dosing tank	8,000 L plastic tanks
Inlet piping	Straight inlet
Outlet piping	Straight inlet
Flow rate control	ABS Ball Valve
Mixing chamber	Mixing took place in the dosing tank
Mixing in reactor	Mixing induced through flow tube convergence at fixed points. Smooth tube surface minimises turbulent boundary layer. Assumption of uniform turbulent plug flow with narrow residence time distribution.
Cooling	External cooling system
Sample ports	Inline taps
UV absorbing material	International Roast™ Coffee
Flow meter	ABB MagMaster
UV spectrophotometer	Shimadzu UV-1201
Power measurement	Fixed output
UV sensors	CLREX NSL5510
Project commissioner	Georgie O'Dwyer of Orica Watercare
Test rig construction	Bob Arnold of UVTA and Orica Watercare
Biodosimetry and collimated beam testing	Dr Paul Monis and Dr Alexandra Keegan of the Australian Water Quality Centre, an operating arm of the South Australian Water Corporation which is in turn a State-owned Corporation of the Government of South Australia
Independent oversight	Dr Daniel Deere, Water Futures Pty Ltd, independent consulting water scientist

3.2. Lamp specifications

Enaqua supplied information on lamp specifications and these are summarised in Table 3-2.

Table 3-2. Lamp specifications.

Item	Details
Type	XUV64 Germicidal UV, Low Pressure, High Output, Non-Amalgam Type, Mercury Vapor
Manufacturer	Enaqua
Part No	001.0619055
Nominal Power Consumption	145 Watts (155 W lamps)
Nominal UV254nm Output	45 Watts Min (53 Watts at 253.7 nm maximum at 100 hours operation)
Nominal Efficiency	32%
Nominal Operating Current	800 mA
Lamp Operating Voltage	220 VAC
Cathode Type	Hot
Nominal UV Intensity at 1 Meter	400 mJ/cm^2 at 1 meter
Connection	Single ended Multi-pin
Nominal Arc Length	1473 mm
Nominal Length	1558 (+/- 3) mm base face to base face, 1565 mm base face to opposite pin
Nominal Quartz Diameter	15 mm
Ozone Production	No measurable amount of ozone
Construction	Quartz (hard glass) with a nominal UV transmission of 90% UV light at 254 nm
UV lamp base	either ceramic or CERAL™ metal ceramic
Nominal rated life	10,000 hours (85% of initial output)
Spectral output new	Low pressure germicidal wavelength
Spectral output aged	Low pressure germicidal wavelength
Mercury content	> 100 mg
Arrangement	Unit A: 2 x parallel Series 35 AFP840™ units each with 2 x lamp stages (banks) in series with CL lamp spacing Unit B: 2 x parallel Series 23 AFP840™ units each with 2 x lamp stages (banks) in series with CL lamp spacing
Lamp age	New lamps: ≥ 140 hours; ≤ 200 hours (used for control) Aged lamps: ≥ 8,000 hours (used for main experiment)

3.3. Flow tube sleeve specifications

Enaqua supplied information on specifications on the flow tubes through which water flows whilst being disinfected and these are summarised in Table 3-3.

Table 3-3. Flow tube sleeve specifications.

Item	Details
Sleeve material	Plastic Activated Fluoropolymer AFP™ 840, low surface charge, non-wetting polymer
UV transmittance at 254 nm	UV transparent: No significant loss of UV transmission over time
Diameter	60 mm 89 mm

3.4. Microbial challenge test organism specifications

The Australian Water Quality Centre supplied information on the microbial challenge test organism used and this is summarised in Table 3-4. MS2 plaques are illustrated in Figure 3-2.

Table 3-4. Microbial challenge test organism.

Item	Details
Challenge organism	MS2 FRNA coliphage ATCC 15597-B1
Host	*E. coli* ATCC 700891-B
Media	As per App D UVDGM except Broth 271 used rather than TSA for host strain
Diluent and blank	1 x phosphate buffered saline

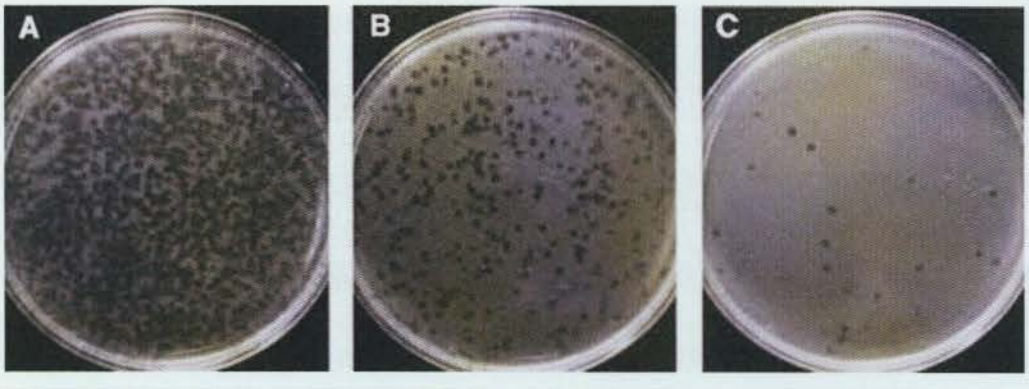


Figure 3-1. Example of MS2 phage plaques (courtesy Dr Alexandra Keegan, AWQC). Plaques are lysed bacteria in a "bacterial lawn" with each plaque being a plaque forming unit (PFU).

3.5. Collimated beam testing apparatus specifications

The Australian Water Quality Centre supplied information on the collimated beam testing apparatus and this is summarised in Table 3-5.

Table 3-5. Collimated beam testing apparatus specifications.

Item	Details
Lamp type	Low pressure
Distance from light source to sample surface	5 cm
Radiometer make and model	International light IL 1400A single UV lamp and ballast
Petri Factor	0.794 +/-0.02
Volume of test suspension	5 +/- 0.1 mL

3.6. Wastewater

Wastewater was sourced from the Heathfield Wastewater Treatment Plant in South Australia and had been treated by primary and secondary process (screening, silt and grit removal, primary settling, conventional activated sludge followed by sedimentation; with no filtration or disinfection). Typical analysis of the wastewater quality is given in

Table 3-6.

Table 3-6. Typical wastewater quality analysis

Analyte	Concentration
Aluminum	0.2 mg/L
Ammonia as N	0.2 mg/L
Bicarbonate	123.7 mg/L
Conductivity	837.8 µS/cm
Free Chlorine	Not detected
Iron	0.78 mg/L
Nitrate + Nitrite as N	7.5 mg/L
Nitrate as Nitrogen	7.3 mg/L
Nitrite as Nitrogen	0.1 mg/L
pH	7.1
Total Phosphorus as P	3.0 mg/L
Suspended Solids	8.8 mg/L
TKN as N	8.1 mg/L
TDS	461 mg/L

3.7. Drinking water

Drinking water was sourced from an urban reticulation system tap in Adelaide, South Australia and had been treated by conventional filtration and disinfection (alum coagulation, flocculation, setting and dual media filtration following by chlorine disinfection). Sodium thiosulphate was used to quench any residual chlorine present in water at the time of analysis.

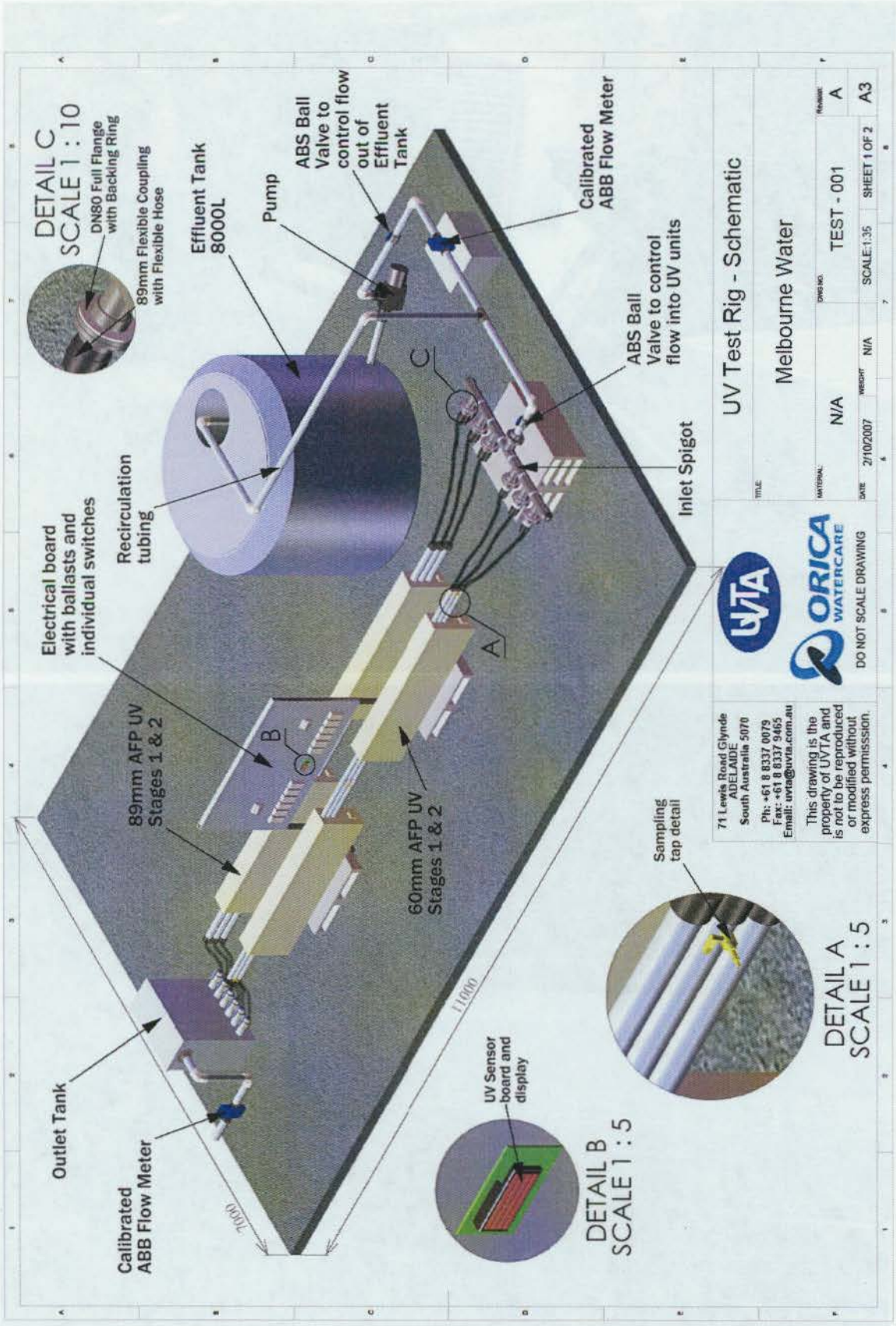


Figure 3-2. Illustration of the test rig layout as used in the validation experiment (note that this drawing is scaled for A3 size print out).

Figure 3-3. Photograph of test rig (top) and reactor chamber with lid removed (bottom).

4. Experimental Design

4.1. Control approach

The reactor control strategy was *Calculated Dose* allowing both UV intensity and flow rate to vary. Lamp power was fixed and was not a variable with the reactor design. The purpose of the validation was to relate a calculated dose that would be predicted as the output of an algorithm that took UV intensity, UV transmissivity and flow rate as inputs. The reactor was set up as two stages in series. The first and second stages each contained independent lamp banks. There were three sampling points: the effluent samples from the first stage of lamp banks represented the influent samples for the second stage.

For operational control, the parameters flow, UV intensity and UV transmissivity can be used. For design of reactors, UVT and flow can be used alone. Therefore, two sets of control equations were derived, with those to be used for design being defined here as design equations.

4.2. Validated dynamic range tested

The dynamic range of conditions tested, within which the calculated dose algorithm is validated, are given in Table 4-1. Note that there is some conservatism in relation to lamp age and the blackening of the internal walls of the reactor.

Table 4-1. Validated dynamic range of parameters tested

Item	Conditions tested	Range validated
Water types	Conventionally treated drinking water Conventionally treated wastewater	Water Wastewater
UVT for water	61.2, 80.9 and 91.3%	61.2 to 91.3% The water UVT range would apply to high UVT tertiary filtered wastewater.
UVT for wastewater	40.3, 49.8 and 62.5%	40.3 to 62.5% The water UVT range would apply to high UVT tertiary filtered wastewater.
Flow tube diameters	60 mm 89 mm	60 mm 89 mm
Flow rate per tube for 60 mm	1.1, 2.3 and 4.2 L/s	1.1 to 4.2 L/s
Flow rate per tube for 89 mm	2.2, 4.4 and 8.1 L/s	2.2 to 8.1 L/s
Lamp failure	All lamps on	All lamps on
Conservative lamp safety factor	Aged lamps all over 8,000 hours	Average lamp age of up to 8,000 hours
Conservative wall safety factor	Blackened inside walls	Stainless steel clean, unclean or blackened inside walls

5. Collimated beam testing results

5.1. Observations

Collimated beam testing was undertaken on each water type on each day of experimentation in accordance with UVDGM protocols. Collimated beam tests were undertaken on each day of testing at 0, 20, 40, 60, 80 and 100 mJ/cm^2. Over the three days of testing, three UVT values were tested: 90, 80 and 60% for potable water and 60, 50 and 40% for wastewater. The results of the collimated beam testing are given in Table 5-1.

Table 5-1. Log N (log_{10} MS2 coliphage pfu/ml) for collimated beam test data.

Dose applied (mJ/cm^2)	Potable 90% UVT log_{10} pfu/ml	Potable 80% UVT log_{10} pfu/ml	Potable 60% UVT log_{10} pfu/ml	Wastewater 60% UVT log_{10} pfu/ml	Wastewater 50% UVT log_{10} pfu/ml	Wastewater 40% UVT log_{10} pfu/ml
0	5.60	5.90	5.78	4.90	5.51	6.23
20	4.74	4.53	4.86	3.42	4.38	5.16
40	3.78	3.90	3.60	ND*	3.58	4.26
60	2.91	2.81	2.97	2.68	2.83	3.37
80	2.11	1.95	2.46	1.78	2.00	2.81
100	1.48	1.60	2.92	1.00	1.00	2.18

*None detected. Note that this does not affect the validity of the results since the regression equation uses the remaining five points.

5.2. UVDGM Analysis

5.2.1. UVDGM regression analysis of observations

Regression analysis with removal of terms that were not significant was used to derive the dose-response equations given in Table 5-2. The dose-response equations were used to predict values for log N_0. Note that some linear and some quadratic equations were used to describe the observed data, the equations used being those that had all significant terms.

Table 5-2. Best-fitting equations describing the collimated beam test data.

Water type (UVT)	Form	Equation for Log N* as a function of applied UV dose	R^2	Significant terms***	Used	**N_0
Potable (90%)	Quadratic	LogN = 0.00008 x Dose^2 – 0.04993 x Dose + 5.640	0.99	All	Yes	5.64
Potable (80%)	Quadratic	LogN = 0.00019 x Dose^2 – 0.06199 x Dose + 5.864	0.99	Not Dose^2 (p=0.0916)	No	N/A
	Linear	LogN = – 0.0433 x Dose + 5.615	0.99	All	Yes	5.62
Potable (60%)	Quadratic	LogN = 0.000442 x Dose^2 – 0.0758 x Dose + 5.935	0.98	All	Yes	5.94
Wastewater (60%)	Quadratic	LogN = 0.00005 x Dose^2 – 0.0404 x Dose + 4.658	0.96	Not Dose & Dose^2 (p=0.177 & 0.824)	No	N/A
	Linear	LogN = – 0.0356 x Dose + 4.607	0.96	All	Yes	4.61
Wastewater (50%)	Quadratic	LogN = 0.00002 x Dose^2 – 0.0459 x Dose + 5.4225	0.99	Not Dose^2 (p=0.6778)	No	N/A
	Linear	LogN = – 0.0435 x Dose + 5.391	0.99	All	Yes	5.39
Wastewater (40%)	Quadratic	LogN = 0.00016 x Dose^2 – 0.0562 x Dose + 6.2271	0.99	All	Yes	6.23

*Log_{10} MS2 concentration.
**Log_{10} MS2 for the no dose condition predicted by the best-fitting model as used.
***The terms that were not significant could be removed from the equation to simplify it.

5.2.2. UVDGM dose-response relationships

Using the N_0 values given in Table 5-2, log inactivation values were generated from the observed collimated beam test data as shown in Table 5-3. The position of the mean UV dose-response curve for the MS2 phage stock solution used lay within the expected range recommended by the UVDGM (the 95-percent prediction interval), as shown in Figure 5-1.

From the data shown in Table 5-3, dose-response relationships were determined using regression for both potable water and wastewater at the three different UVT levels tested and these equations are shown in Table 5-4.

The best-fitting relationships for the three potable water UVT levels were not significantly different from one another and were combined to provide a single relationship. The best-fitting relationships for the three wastewater UVT levels were significantly different from one another were not combined. Therefore, a total of four dose-response relationships were carried forward for use in the biodosimetry. Each relationship was constrained by a zero intercept.

Table 5-3. Log I (log_{10} N_0/N) MS2 coliphage pfu/ml for collimated beam test data.

Dose applied (mJ/cm^2)	Potable 90% UVT log_{10} pfu/ml	Potable 80% UVT log_{10} pfu/ml	Potable 60% UVT log_{10} pfu/ml	Wastewater 60% UVT log_{10} pfu/ml	Wastewater 50% UVT log_{10} pfu/ml	Wastewater 40% UVT log_{10} pfu/ml
0	0.04	-0.29	0.16	-0.29	-0.12	-0.00
20	0.90	1.09	1.08	1.19	1.01	1.07
40	1.86	1.72	2.34	ND*	1.81	1.97
60	2.73	2.81	2.97	1.93	2.57	2.86
80	3.53	3.67	3.48	2.83	3.39	3.42
100	4.16	4.02	3.02	3.61	4.39	4.05

*None detected. Note that this does not affect the validity of the results since the regression equation uses the remaining five points.

Table 5-4. Best-fitting dose-response relationships derived from the collimated beam test data.

Water type (UVT)	Form	Equation for RED* as a function of Log I**	R^2	Significant terms
Potable (combined)	Linear	RED = 23.226 x logI	0.98	All
Wastewater (60%)	Linear	RED = 27.703 x logI	0.99	All
Wastewater (50%)	Linear	RED = 22.968 x logI	0.99	All
Wastewater (40%)	Linear	RED = 23.033 x logI	0.99	All

*Reduction Equivalent UV Dose for MS2; **Log_{10} MS2 inactivation calculated as Log (N_0/N) at a particular dose.

5.2.3. UVDGM uncertainty in dose-response (UDR)

The predicted dose-response relationships from the equations given in Table 5-4 were compared with the observed data given in Table 5-1. Using the UVDGM equation B.7 the uncertainty for the dose-response relationships (UDR) are given in Table 5-5 for 1 log inactivation. Since all UDR values were > 30%, UDR was included in the uncertainty in validation (UVAL) term. Individual UDR values could be used for defining specific reactor log credits for tight operating ranges.

Table 5-5. Uncertainty in the dose-response equations (UDR) for the relationships used.

Media	Count	t-statistic (0.05)	Standard deviation	UDR
Potable (combined)	18	2.552	9.135	100.37%
Wastewater (60%)	6	3.143	4.92	67.14%
Wastewater (50%)	6	3.143	2.32	31.75%
Wastewater (40%)	5	3.365	8.305	100.88%

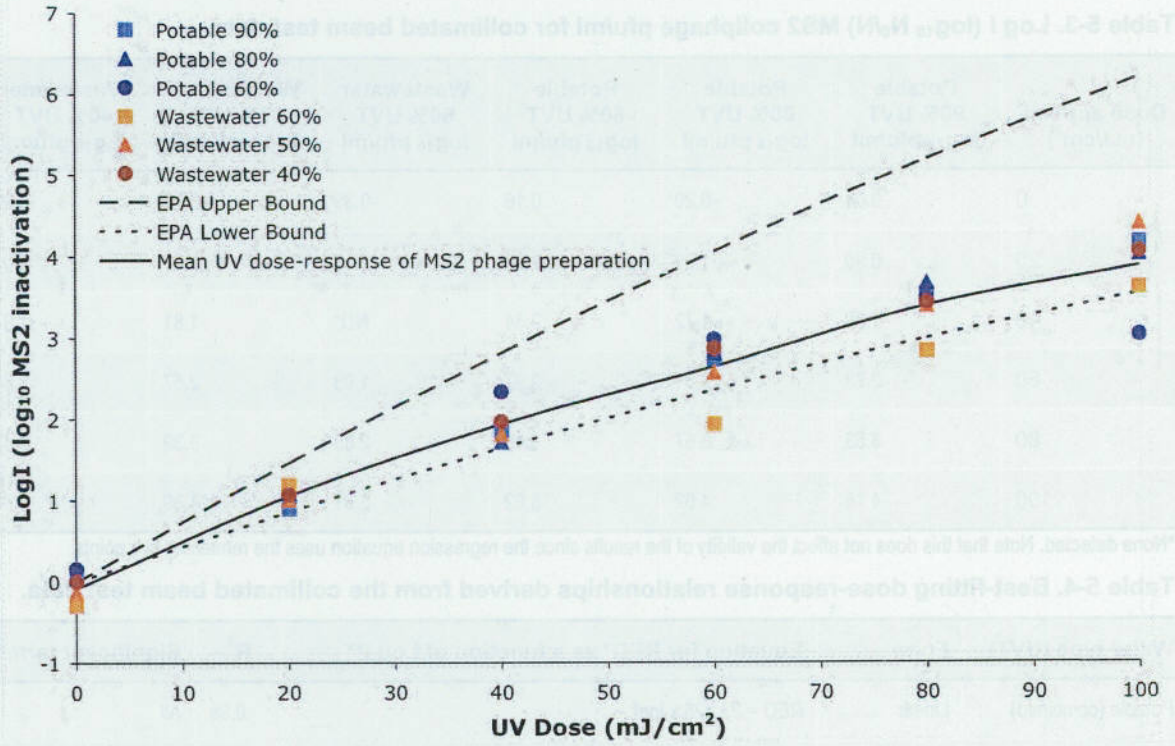


Figure 5-1. UV dose-response of MS2 coliphage from the collimated bean testing work. Log I is plotted against the applied dose. Shown are the upper and lower bounds of the USEPA prediction intervals.

5.3. NWRI Analysis

5.3.1. NWRI dose-response relationships

Using the values given in Table 5-1, log inactivation values were generated from the observed collimated beam test data as shown in Table 5-6. The position of the mean UV dose-response curve for the MS2 phage stock solution used lay within the expected range recommended by the NWRI recommended range as shown in Figure 5-2. From the data shown in Table 5-6, dose-response relationships were determined using regression for both potable water and wastewater at the three different UVT levels tested and these equations are shown in Table 5-7. The best-fitting relationships for the three averaged potable water UVT levels and three wastewater UVT levels were found. Therefore, a total of two dose-response relationships were carried forward for use in the biodosimetry.

Table 5-6. -Log$_{10}$ (N/N$_0$) MS2 coliphage pfu/ml for collimated beam test data.

Dose applied (mJ/cm^2)	Potable (log$_{10}$ pfu/ml)	Wastewater (log$_{10}$ pfu/ml)
20	1.05	1.23
40	2.00	1.63
60	2.86	2.59
80	3.58	3.35
100	3.76	4.16

Table 5-7. Best-fitting dose-response relationships derived from the collimated beam test data.

Water type	Form	Equation for RED* as a function of LogI**	R^2	Significant terms**
Potable (combined)	Linear	RED = 27.3 x logI – 12.4	0.96	All except the intercept (p = 0.29)
Wastewater (combined)	Linear	RED = 26.1 x logI – 7.63	0.99	All except the intercept (p = 0.19)

*Reduction Equivalent UV Dose for MS2; **Log$_{10}$ MS2 inactivaticn calculated as -Log (N/N$_0$) at a particular dose.
**The terms that were not significant could be removed from the equation to simplify it.

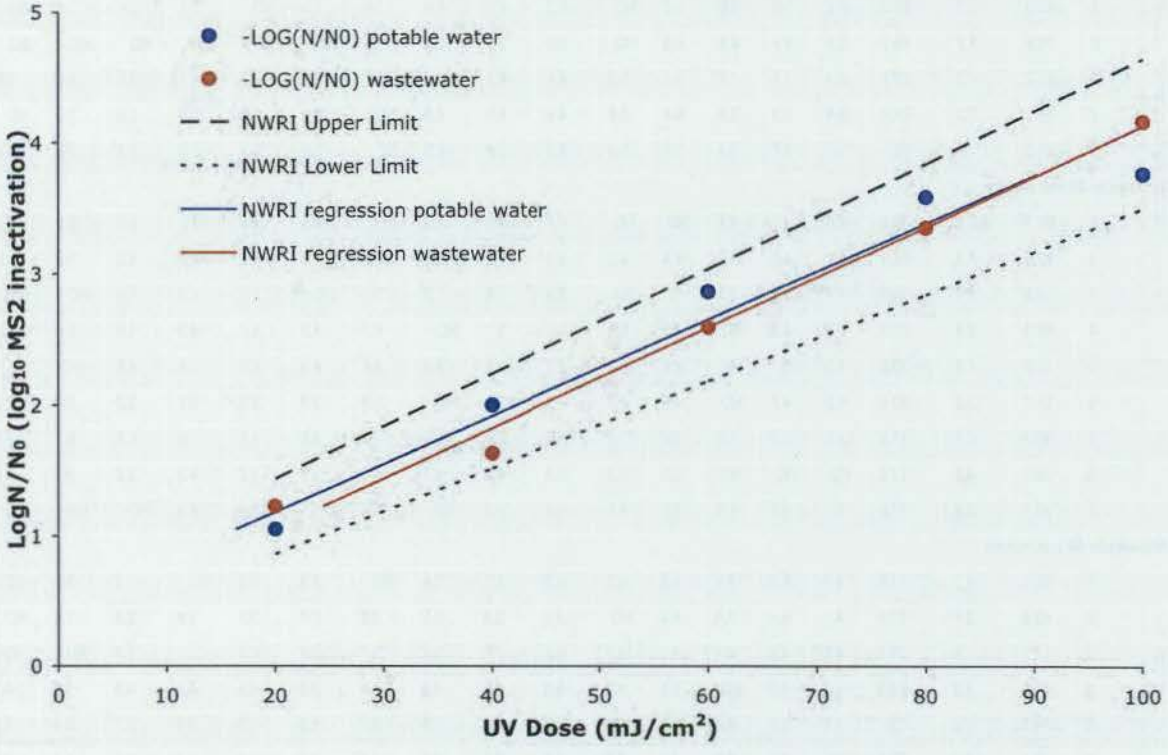


Figure 5-2. UV dose-response of MS2 coliphage from the collimated bean testing work. –Log (N/N$_0$) is plotted against the applied dose. Shown are the upper and lower bounds of the NWRI 80% acceptance intervals within which 80% of the data must lie.

6. Biodosimetry

6.1. Observations

The results of the biodosimetry are given in Table 6-1.

Table 6-1. Biodosimetry results shown as log_{10} MS2 pfu/ml for five replicates.

Condition	UVT (%)	Flow (L/s)	UVI (value)	Log_{10} influent MS2 (pfu/ml)					Log_{10} effluent stage 1 MS2 (pfu/ml)					Log_{10} effluent stage 2 MS2 (pfu/ml)				
Potable Water 89 mm reactor																		
1	94.1	8.1	88.5	ND	4.6	4.7	ND	ND	ND	4.3	3.5	ND	ND	ND	1.8	2.9	ND	2.5
2	89.9	4.4	88.5	ND	ND	5.3	5.2	5.0	2.6	ND	2.8	2.9	2.5	ND	ND	1.8	1.0	1.0
3	89.9	2.2	88.5	5.2	4.9	5.2	5.0	5.3	2.6	2.9	3.1	2.7	2.8	ND	1.0	ND	ND	ND
4	83.0	8.1	63.3	6.3	6.0	5.7	5.7	5.5	5.1	4.8	4.7	4.8	5.0	4.5	4.3	3.8	ND	3.2
5	79.8	4.3	63.3	5.1	4.3	4.5	4.7	4.5	3.9	ND	ND	ND	ND	2.8	2.7	ND	ND	ND
6	79.8	2.3	63.3	5.2	5.3	5.3	4.8	ND	3.3	4.1	ND	3.3	ND	1.8	1.0	2.7	1.8	ND
7	61.2	8.1	33.7	5.3	5.1	5.0	3.6	ND	4.9	ND	ND	ND	ND	4.5	3.8	4.2	4.6	ND
8	61.2	4.3	33.7	5.3	4.5	4.5	5.4	5.2	4.5	5.3	4.6	4.6	5.3	4.0	ND	4.3	4.1	4.5
9	61.2	2.3	33.7	5.0	5.3	5.1	ND	ND	4.5	4.0	4.0	ND	ND	3.0	3.0	4.0	3.3	ND
Potable Water 60 mm reactor																		
1	89.9	4.2	102.0	4.1	4.3	ND	ND	ND	2.5	1.7	ND	ND	ND	ND	ND	ND	ND	ND
2	94.1	2.2	102.0	ND	ND	4.8	ND	ND	ND	ND	2.3	ND	ND	ND	ND	ND	ND	ND
3	89.9	1.1	102.0	4.5	3.8	4.0	4.5	ND	1.0	1.0	ND	ND	ND	ND	ND	ND	ND	ND
4	79.8	4.2	89.2	5.1	4.5	4.3	5.3	5.3	4.4	3.1	2.8	3.0	2.7	ND	1.7	2.0	ND	2.8
5	83.0	2.2	89.2	6.0	5.8	5.6	6.3	ND	4.2	4.3	4.1	3.8	3.6	ND	2.1	2.4	2.4	ND
6	79.8	1.2	89.2	5.1	5.1	4.8	4.5	ND	2.5	2.1	2.3	1.8	ND	ND	ND	ND	ND	ND
7	61.2	4.2	76.6	5.3	4.7	4.6	5.3	5.2	4.1	4.7	ND	ND	5.0	4.7	4.1	4.4	3.6	3.9
8	61.2	2.3	76.6	5.4	5.3	5.5	5.4	5.4	4.9	4.9	4.5	ND	4.6	3.3	3.0	3.5	3.3	ND
9	61.2	1.2	76.6	5.1	5.1	5.4	5.0	5.4	4.3	2.8	4.3	ND	3.0	2.7	2.6	2.7	2.6	2.6
Wastewater 89 mm reactor																		
1	62.5	8.2	36.1	4.8	4.7	4.4	ND	ND	4.4	4.3	4.0	ND	4.5	4.0	4.4	4.2	3.6	4.0
2	62.5	4.4	36.1	ND	4.0	4.7	4.4	4.3	4.4	4.2	3.7	4.0	4.3	4.2	4.3	4.0	3.0	3.8
3	62.5	2.1	36.1	4.7	4.0	4.7	ND	ND	2.9	1.0	1.8	ND	ND	1.7	2.3	1.0	ND	ND
4	49.3	8.1	23.5	5.3	4.9	ND	4.6	5.1	5.1	5.1	ND	4.7	4.8	4.4	4.3	4.9	4.4	4.5
5	51.0	4.4	23.5	4.3	5.1	5.1	4.6	5.2	4.7	4.6	4.8	4.4	4.8	4.4	3.6	4.8	4.5	4.7
6	51.0	2.3	23.5	4.5	4.6	ND	4.3	4.2	4.2	2.8	ND	3.9	3.3	2.3	2.7	2.9	2.8	2.7
7	40.9	8.1	17.6	4.6	5.2	5.2	5.2	5.3	5.2	5.1	ND	4.7	4.6	4.6	4.6	4.5	4.1	4.0
8	39.1	4.3	17.6	ND	ND	ND	5.3	5.2	4.8	4.0	4.7	4.4	4.9	4.7	4.3	3.7	4.3	4.8
9	39.1	2.2	17.6	4.6	4.7	4.9	5.3	4.9	4.4	4.6	ND	4.8	5.1	3.9	4.3	ND	ND	4.1
Wastewater 60 mm reactor																		
1	62.5	4.2	77.6	4.3	4.5	4.4	4.5	4.3	4.0	4.3	3.4	ND	3.3	2.8	ND	2.7	2.6	ND
2	62.5	2.1	77.6	4.1	4.4	3.8	4.3	ND	2.9	2.6	3.0	2.8	3.0	2.3	2.8	2.3	1.9	ND
3	62.5	1.1	77.6	4.5	4.7	4.6	4.3	4.6	4.0	2.8	2.7	2.7	2.1	1.0	1.0	1.7	ND	ND
4	51.0	4.2	72.2	4.8	4.5	ND	5.1	4.8	5.0	4.0	4.6	4.6	5.0	4.5	4.2	4.3	3.0	4.7
5	49.3	2.3	72.2	5.1	4.8	4.4	4.3	4.3	4.0	4.6	3.6	3.0	1.8	2.5	3.1	3.2	2.8	3.2
6	49.3	1.1	72.2	ND	4.5	4.9	4.8	3.7	2.6	2.8	2.8	3.1	2.9	1.0	1.0	1.0	1.0	2.5
7	40.9	4.1	69.9	5.0	5.1	4.9	4.8	4.9	4.9	4.9	ND	4.7	4.0	3.5	4.3	4.5	4.4	3.8
8	39.1	2.2	69.9	5.4	5.1	5.0	4.9	5.1	4.6	4.8	ND	ND	ND	ND	3.7	3.9	ND	ND
9	40.9	1.2	69.9	4.5	4.8	4.7	5.0	ND	4.4	4.6	4.0	ND	ND	2.9	2.9	3.1	3.0	ND

ND: Not determined due to confluence (too many to count), or too few to count, per plate

6.2. UVDGM analysis

6.2.1. UVDGM log reductions achieved by the reactors

A summary of the observed log reductions achieved by the reactors is given in Table 6-2 for the UVDGM method.

Table 6-2. Biodosimetry results shown as log_{10} MS2 pfu/ml for five replicates using UVDGM method.

Condition	Flow (L/s)	UVT (%)	UVI (value)	Coefficient of dose-response equation	Mean Logl (1 stage)	RED for MS2 (1 stage)	Mean Logl (2 stages)	RED MS2 (2 stages)
Potable Water 89 mm reactor								
1	8.1	94.1	88.5	23.2	0.8	18.7	2.3	53.1
2	4.4	89.9	88.5	23.2	2.4	56.0	3.9	89.7
3	2.2	89.9	88.5	23.2	2.3	53.0	3.9	90.9
4	8.1	83.0	63.3	23.2	0.9	21.9	1.9	44.3
5	4.3	79.8	63.3	23.2	1.2	28.0	2.0	45.6
6	2.3	79.8	63.3	23.2	1.5	35.3	3.3	77.4
7	8.1	61.2	33.7	23.2	0.4	8.3	0.5	11.7
8	4.3	61.2	33.7	23.2	0.1	2.5	0.9	20.4
9	2.3	61.2	33.7	23.2	1.0	23.4	1.8	42.4
Potable Water 60 mm reactor								
1	4.2	89.9	102	23.2	2.1	49.4	ND	ND
2	2.2	94.1	102	23.2	2.6	59.7	ND	ND
3	1.1	89.9	102	23.2	3.2	73.6	ND	ND
4	4.2	79.8	89.2	23.2	1.7	39.9	2.6	59.3
5	2.2	83.0	89.2	23.2	1.8	42.6	3.6	83.2
6	1.2	79.8	89.2	23.2	2.7	62.6	ND	ND
7	4.2	61.2	76.6	23.2	0.5	11.4	0.9	20.4
8	2.3	61.2	76.6	23.2	0.7	15.3	2.1	49.5
9	1.2	61.2	76.6	23.2	1.6	37.7	2.5	59.0
Wastewater 89 mm reactor								
1	8.2	62.5	36.1	27.7	0.4	11.9	0.4	11.5
2	4.4	62.5	36.1	27.7	0.3	7.9	0.6	15.6
3	2.1	62.5	36.1	27.7	2.6	71.4	2.8	78.0
4	8.1	49.3	23.5	23.0	0.0	0.6	0.6	12.9
5	4.4	51.0	23.5	23.0	0.2	4.8	0.5	10.7
6	2.3	51.0	23.5	23.0	0.8	19.5	1.8	40.4
7	8.1	40.9	17.6	23.0	0.2	3.5	0.7	16.9
8	4.3	39.1	17.6	23.0	0.6	14.7	0.8	17.3
9	2.2	39.1	17.6	23.0	0.2	3.9	0.7	15.3
Wastewater 60 mm reactor								
1	4.2	62.5	77.6	27.7	0.7	18.4	1.8	48.7
2	2.1	62.5	77.6	27.7	1.3	37.0	1.8	50.3
3	1.1	62.5	77.6	27.7	1.7	46.5	3.4	93.9
4	4.2	51.0	72.2	23.0	0.2	3.4	0.7	15.9
5	2.3	49.3	72.2	23.0	1.2	26.8	1.6	37.1
6	1.1	49.3	72.2	23.0	1.6	36.0	3.1	71.0
7	4.1	40.9	69.9	23.0	0.3	7.9	0.8	19.4
8	2.2	39.1	69.9	23.0	0.5	12.3	1.3	29.0
9	1.2	40.9	69.9	23.0	0.3	7.5	1.8	41.3

ND: Not determined due to confluence (too many to count), or too few to count, per plate

6.2.2. UVDGM equations to predict the reduction equivalent dose

Two types of equations were derived from the data presented in Table 6-1 and combined with the dose-response equations given in Table 5-4. These two types of equations were:

- Control equations that use UVI (UV intensity), UVT (UV transmissivity) and flow rate as independent variables to predict calculated (RED) reduction equivalent dose; and
- Design equations that use UVT and flow rate as independent variables to predict calculated (RED) reduction equivalent dose.

The equations derived are given in Table 6-3 for control and in Table 6-4 for design. RED values less than zero were removed from all calculations, hence the value of N is not always the same for all results. The intercept was set to zero. A range of regression equations were fit to the observations. The strong colinearity between UVI and UVT mean that inevitably many of the equations that include both UVI and UVT find one of these terms to be insignificant. In predicting inactivation for design and control purposes, equations for which all terms are significant are preferred and would be used in preference to equations in which one or more terms are not significant. However, all of the equations can be used within the dynamic range within which they interpolate. When any equation is used, a check for conservatism can be made by comparing predicted with actual values.

Table 6-3. RED calculation control equations.

Water type (diameter) [stages]	*RED equation	N	R^2	Significant terms**
Potable (89 mm) [1 stage]	LogRED = 0.582 x log(1/flow) + 0.871 x logUVI + 0.128 x logUVT	25	0.99	All but UVT (p = 0.699)
Potable (89 mm) [2 stages]	LogRED = 0.456 x log(1/flow) + 1.387 x logUVI – 0.255 x logUVT	26	0.99	All but UVT (p = 0.483)
Potable (60 mm) [1 stage]	LogRED = 0.734 x log(1/flow) – 6.383 x logUVI + 7.541 x logUVT	29	0.97	All
Potable (60 mm) [2 stages]	LogRED = 0.944 x log(1/flow) – 4.320 x logUVI + 5.606 x logUVT	20	0.98	All
Wastewater (89 mm) [1 stage]	LogRED = 0.569 x log(1/flow) + 1.696 x logUVI – 0.555 x logUVT	26	0.92	All but UVT & UVI (p = 0.545 & 0.131)
Wastewater (89 mm) [2 stages]	LogRED = 0.754 x log(1/flow) – 1.148 x logUVI + 1.968 x logUVT	30	0.94	All but UVI (p = 0.264)
Wastewater (60 mm) [1 stage]	LogRED = 0.639 x log(1/flow) – 1.567 x logUVI + 2.549 x logUVT	33	0.94	All
Wastewater (60 mm) [2 stages]	LogRED = 0.970 x log(1/flow) + 0.469 x logUVI + 0.583 x logUVT	34	0.97	All but UVT & UVI (p = 0.501 & 0.554)

*Reduction Equivalent UV Dose for MS2.
**The terms that were not significant could be removed from the equation to simplify it.

Table 6-4. RED calculation design equations.

Water type (diameter) [stages]	*RED equation	N	R^2	Significant terms**
Potable (89 mm) [1 stage]	LogRED = 0.634 x log(1/flow) + 0.968 x logUVT	25	0.99	All
Potable (89 mm) [2 stages]	LogRED = 0.513 x log(1/flow) +1.049 x logUVT	26	0.98	All
Potable (60 mm) [1 stage]	LogRED = 0.731 x log(1/flow) + 0.939 x logUVT	29	0.96	All
Potable (60 mm) [2 stages]	LogRED = 0.851 x log(1/flow) +1.079 x logUVT	20	0.98	All
Wastewater (89 mm) [1 stage]	LogRED = 0.616 x log(1/flow) + 0.850 x logUVT	26	0.91	All
Wastewater (89 mm) [2 stages]	LogRED = 0.705 x log(1/flow) + 1.009 x logUVT	30	0.94	All
Wastewater (60 mm) [1 stage]	LogRED = 0.702 x log(1/flow) + 0.854 x logUVT	33	0.94	All
Wastewater (60 mm) [2 stages]	LogRED = 0.958 x log(1/flow) + 1.094 x logUVT	34	0.97	All

*Reduction Equivalent UV Dose for MS2.
**The terms that were not significant could be removed from the equation to simplify it.

6.2.3. UVDGM dose demonstrated by biodosimetry

Design curves for the dose demonstrated by the biodosimetry are given here for the 60 mm wastewater reactor in Figure 6-1. The approach used can be followed to generate similar design curves for other reactors, predicting the dose that is likely to be applied by reactors under particular design conditions.

The curves demonstrate the best estimate for the RED for viral inactivation for the reactors based on the conditions tested. Assigning 'log credits' is a regulatory process and an example for potable water using the UVDGM is given in the following section.

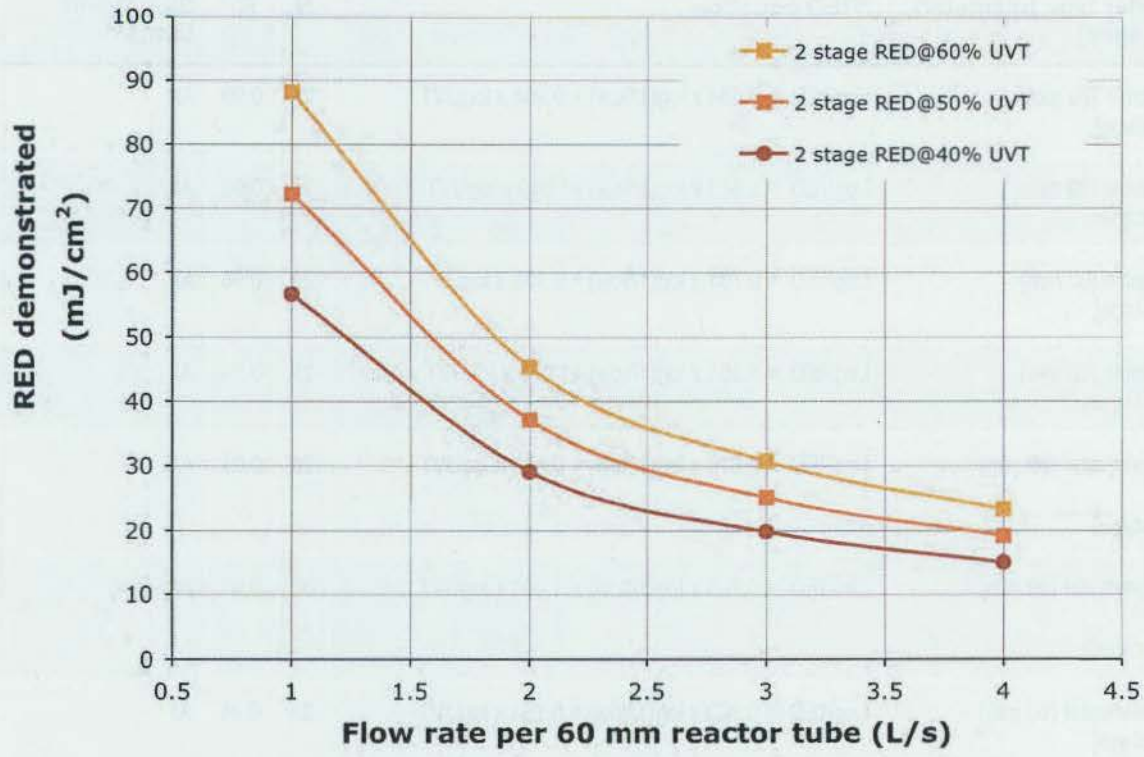


Figure 6-1. Example design curve for 60 mm wastewater 2 stage reactor (UVDGM).

6.2.4. UVDGM Validation Factor

For calculating the USEPA log credits, some additional uncertainties are required to be included for potable water reactors at high UVTs. The Validation Factor (VF) was determined using a range of input data as described in the UVDGM. The following sets out how each component was derived.

RED Bias

For the body of this report, the RED Bias (BRED) is set at 1.0, suitable for defining the RED applicable to viruses (UVDGM Appendix G) for all UVTs and all log reduction values. The reason that there is no significant BRED in predicting viral log inactivation credits is that MS2 coliphage was used which has a sensitivity and response similar to pathogenic viruses.

For *Cryptosporidium*, BRED is determined based on Appendix G of the UVDGM on a case-by-case basis for the minimum UVT and log reduction designed. The *Cryptosporidium* BRED is then incorporated into the Validation Factor in place of the value 1.0.

Uncertainty of validation

The uncertainty of validation (UVAL) is derived from the uncertainty in inactivation (UIN), the uncertainty in the dose-response relationship (UDR) and uncertainty in the UV sensor readings (US).

Inactivation uncertainty (UIN)

UIN needs to be derived each time. The key data are the standard deviation and the value of n from which the standard deviation was derived in comparing the calculated with the measured dose for each determination. These data are shown in Table 6-5 for control and in Table 6-6 for design.

Dose-response uncertainty (UDR)

UDR was derived as described in Section 5.2.3 and the highest values observed, being 100.37% and 100.88% were used in calculating UVAL for potable water and wastewater, respectively. In reactor design and operation, alternative values may be used where these fit better to the specific range.

UV sensor uncertainty (US)

US was derived as follows. All values shown in Table 6-1 were as determined from the experiments undertaken on the relevant day except the UV intensity (UVI) values from the UV sensors which were derived from a static run of the same test rigs shortly after the biodosimetry. The UVI values were obtained by running water through the test rig at the UVT levels representing those used during the biodosimetry for both water and wastewater. Each duty UV sensor was removed and replaced with three reference sensors to allow for the determination of the UV sensor uncertainty as described in the UVDGM under equation 5.5 (Table 6-7). The highest value observed, 10.36%, was used.

6.2.5. Using the outcomes of the UVDGM validation

The data presented in this validation report can be used to support the design, and the assignment of log credits, to specific reactors. A simple calculation worksheet has been set up to enable the calculation of RED values for design and control purposes as well as the inactivation log credits for regulatory purposes. The calculation worksheet takes into account site-specific information on flow rate, UVT range, water type, target pathogen for log credit, log credit required, etc. Log reductions are additive for multiple stages, e.g. four stages can be designed based on doubling the two stage reactor predictions.

Table 6-5. Inputs to UIN* for determining the Validation Factor for the control equations.

Water type (diameter) [stages]	*RED equation	N	t-crit (0.05)	Standard deviation
Potable (89 mm) [1 stage]	LogRED = 0.582 x log(1/flow) + 0.871 x logUVI + 0.128 x logUVT	25	2.06	9.5
Potable (89 mm) [2 stages]	LogRED = 0.456 x log(1/flow) + 1.387 x logUVI – 0.255 x logUVT	26	2.06	12.7
Potable (60 mm) [1 stage]	LogRED = 0.734 x log(1/flow) – 6.383 x logUVI + 7.541 x logUVT	29	2.05	15.8
Potable (60 mm) [2 stages]	LogRED = 0.944 x log(1/flow) – 4.320 x logUVI + 5.606 x logUVT	20	2.09	14.2
Wastewater (89 mm) [1 stage]	LogRED = 0.569 x log(1/flow) + 1.696 x logUVI – 0.555 x logUVT	26	2.06	13.6
Wastewater (89 mm) [2 stages]	LogRED = 0.754 x log(1/flow) – 1.148 x logUVI + 1.968 x logUVT	30	2.04	15.5
Wastewater (60 mm) [1 stage]	LogRED = 0.639 x log(1/flow) – 1.567 x logUVI + 2.549 x logUVT	33	2.04	13.0
Wastewater (60 mm) [2 stages]	LogRED = 0.970 x log(1/flow) + 0.469 x logUVI + 0.583 x logUVT	34	2.04	14.9

*Uncertainty in inactivation.

Table 6-6. Inputs to UIN* for determining the Validation Factor for the design equations.

Water type (diameter) [stages]	*RED equation	N	t-crit (0.05)	Standard deviation
Potable (89 mm) [1 stage]	LogRED = 0.634 x log(1/flow) + 0.968 x logUVT	25	2.06	11.6
Potable (89 mm) [2 stages]	LogRED = 0.513 x log(1/flow) +1.049 x logUVT	26	2.06	18.4
Potable (60 mm) [1 stage]	LogRED = 0.731 x log(1/flow) + 0.939 x logUVT	29	2.05	16.0
Potable (60 mm) [2 stages]	LogRED = 0.851 x log(1/flow) +1.079 x logUVT	20	2.09	17.2
Wastewater (89 mm) [1 stage]	LogRED = 0.616 x log(1/flow) + 0.850 x logUVT	26	2.06	15.4
Wastewater (89 mm) [2 stages]	LogRED = 0.705 x log(1/flow) + 1.009 x logUVT	30	2.04	14.5
Wastewater (60 mm) [1 stage]	LogRED = 0.702 x log(1/flow) + 0.854 x logUVT	33	2.04	13.4
Wastewater (60 mm) [2 stages]	LogRED = 0.958 x log(1/flow) + 1.094 x logUVT	34	2.04	15.0

*Uncertainty in inactivation.

Table 6-7. UV sensor uncertainty assessment data.

Sensor number	Duty	Reference #1	Reference #2	Reference #3	Us (UV sensor)
1	102	94	100	101.3	3.62%
2	88.8	101.2	97.5	98.5	10.36%
3	89.8	93.8	73.9	92.2	3.66%
4	88.5	92	65	86.2	9.17%

6.2.6. Visualising the UVDGM output

A series of plots (from Figure 6-2 to Figure 6-9) compare the UVDGM Validated Dose for viral inactivation log credits with the observed MS2 RED from the biodosimetry experiments. These plots demonstrate how conservative the UVDGM approach is in predicting inactivation capability of UV reactors, demonstrating that the approach adopted in this reactor validation was a conservative one.

In practice, the actual log reduction values for MS2 can be used to provide a best estimate of UV reactor performance for viral inactivation, that is, the regression equations without the Validation Factor. The Validation Factor is only required to provide a highly conservative log inactivation credit for specific pathogens for regulatory purposes in US drinking water applications.

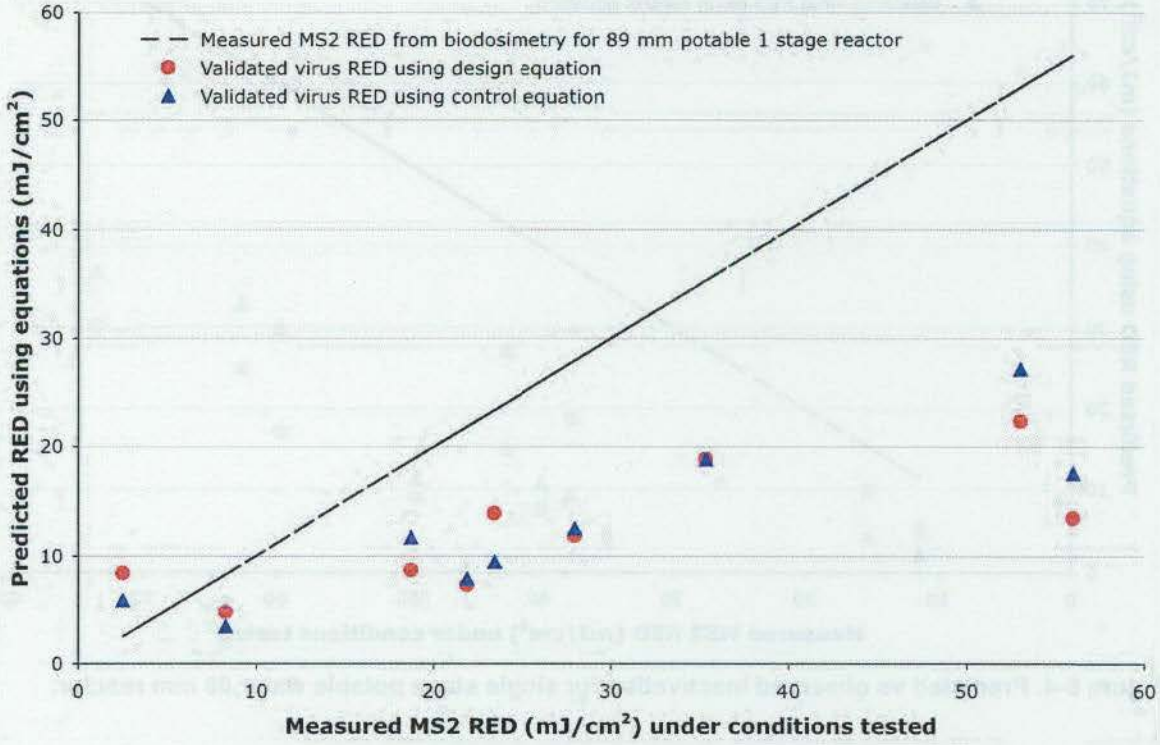


Figure 6-2. Predicted vs observed inactivation for single stage potable water 89 mm reactor.

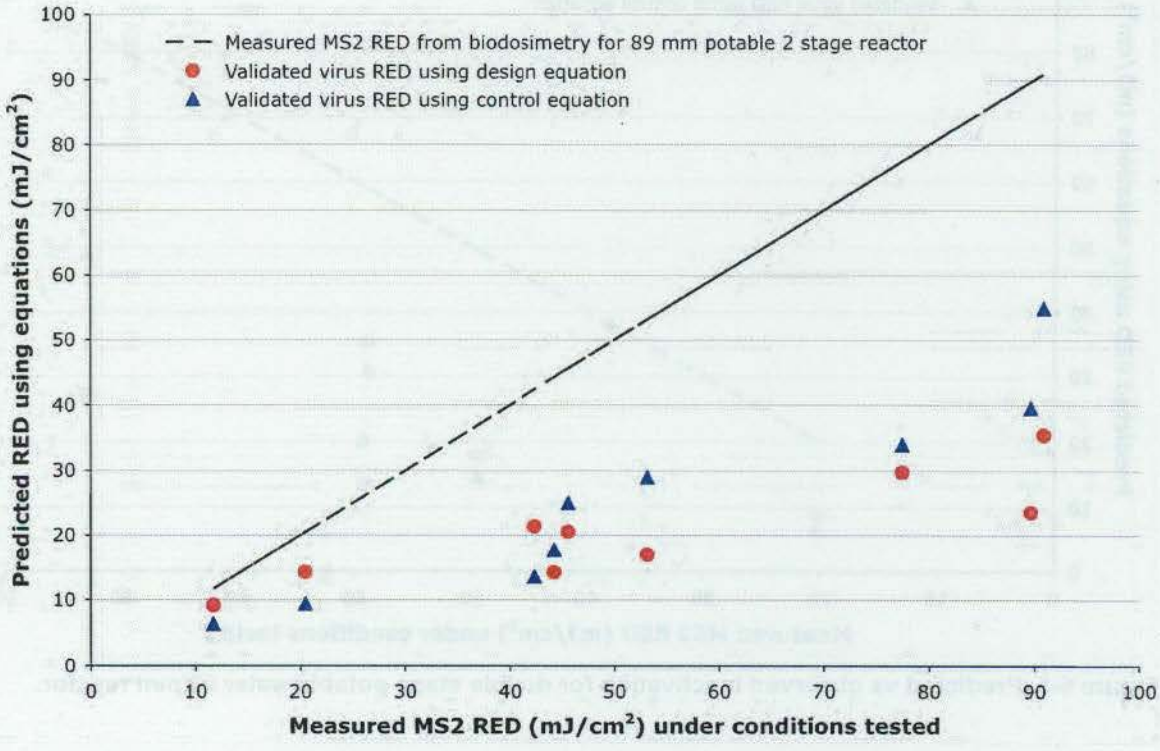


Figure 6-3. Predicted vs observed inactivation for double stage potable water 89 mm reactor.

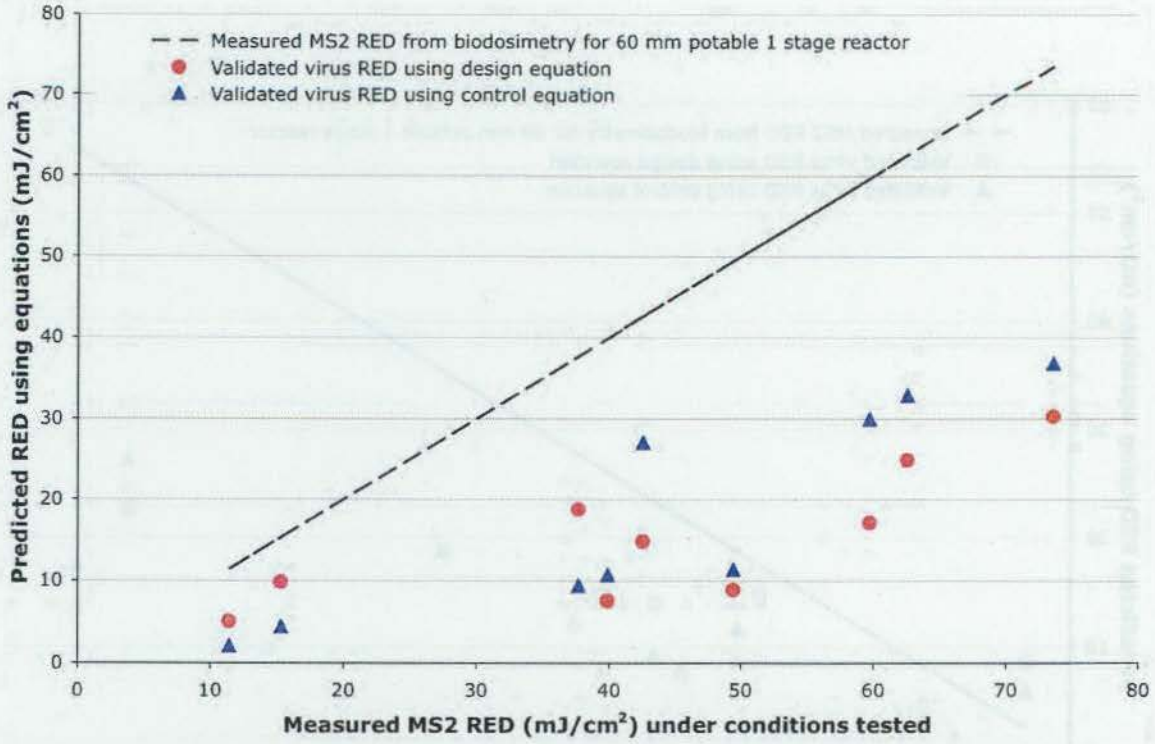


Figure 6-4. Predicted vs observed inactivation for single stage potable water 60 mm reactor.

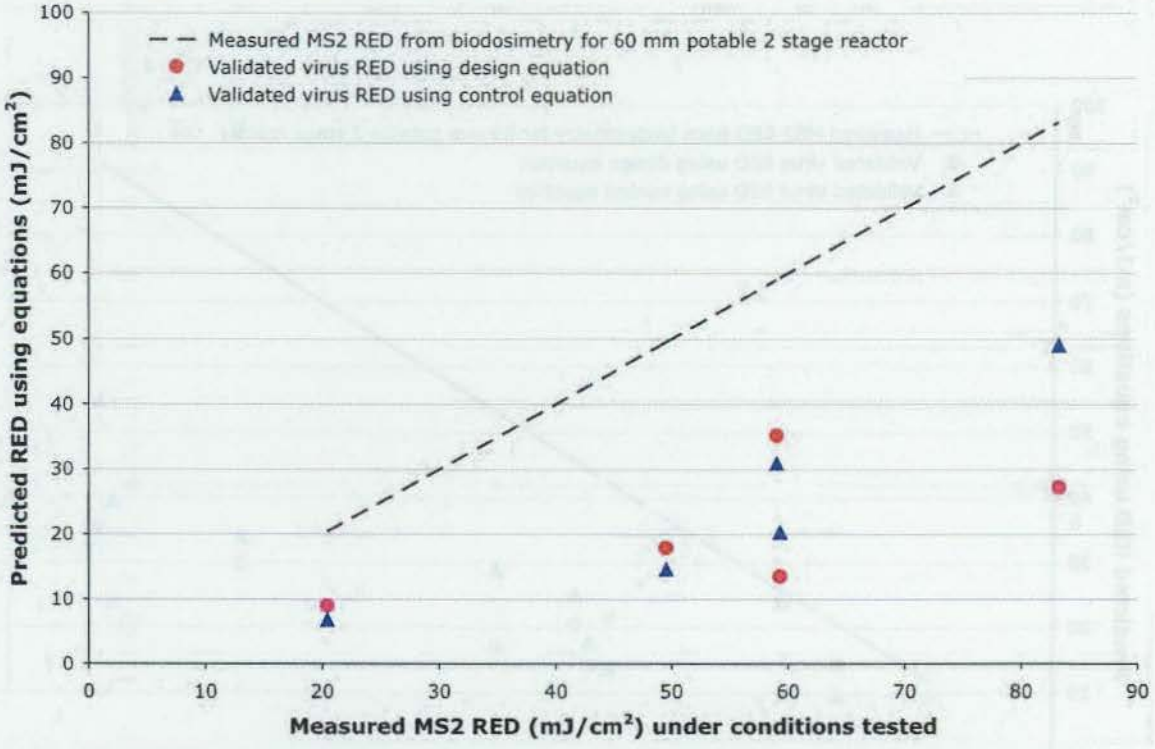


Figure 6-5. Predicted vs observed inactivation for double stage potable water 60 mm reactor.

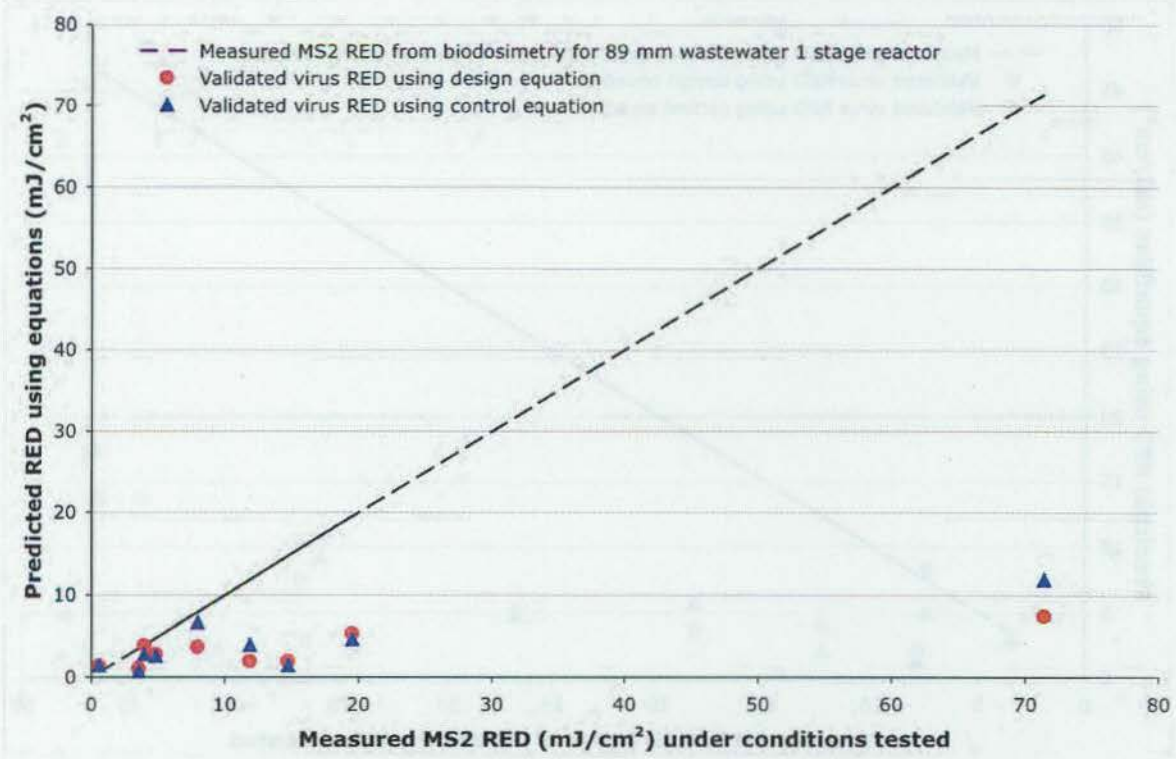


Figure 6-6. Predicted vs observed inactivation for single stage wastewater 89 mm reactor.

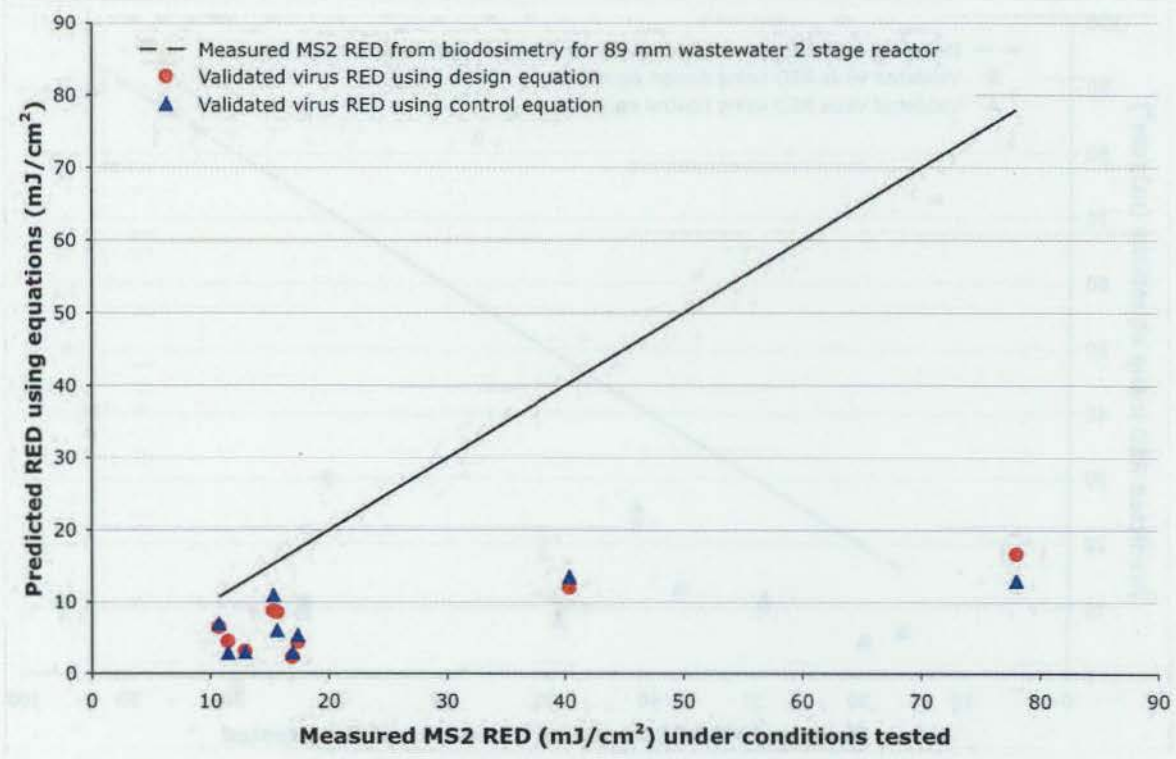


Figure 6-7. Predicted vs observed inactivation for double stage wastewater 89 mm reactor.

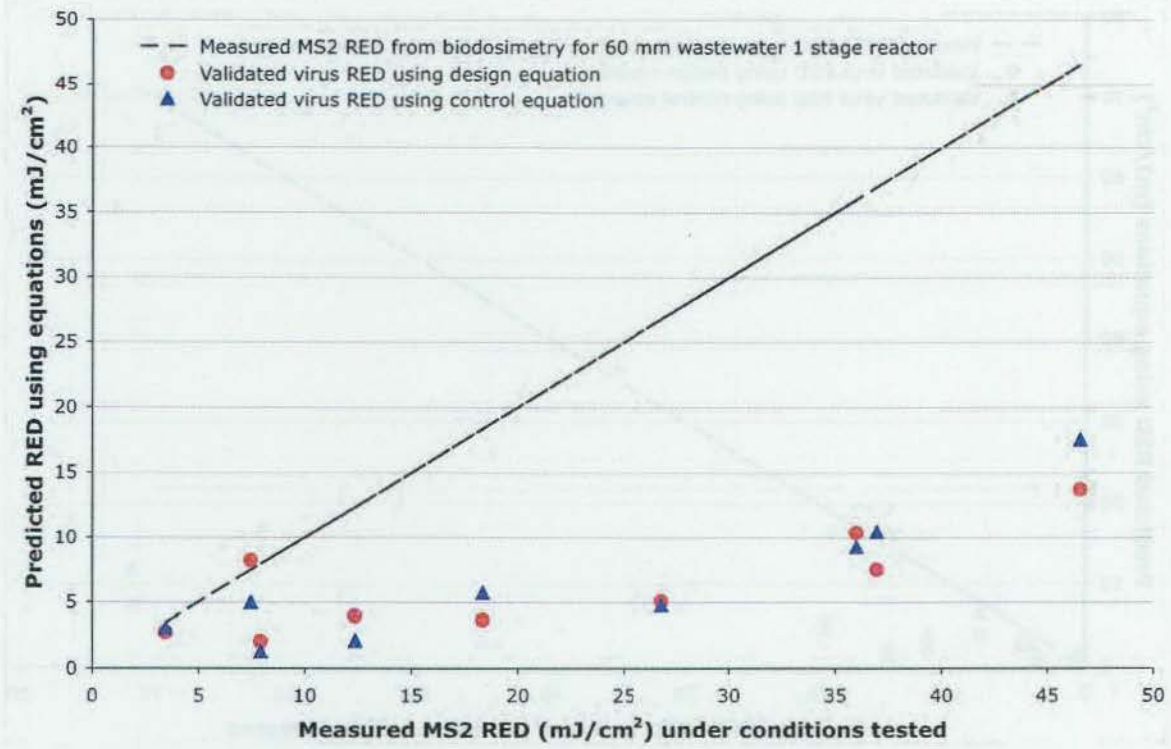


Figure 6-8. Predicted vs observed inactivation for single stage wastewater 60 mm reactor.

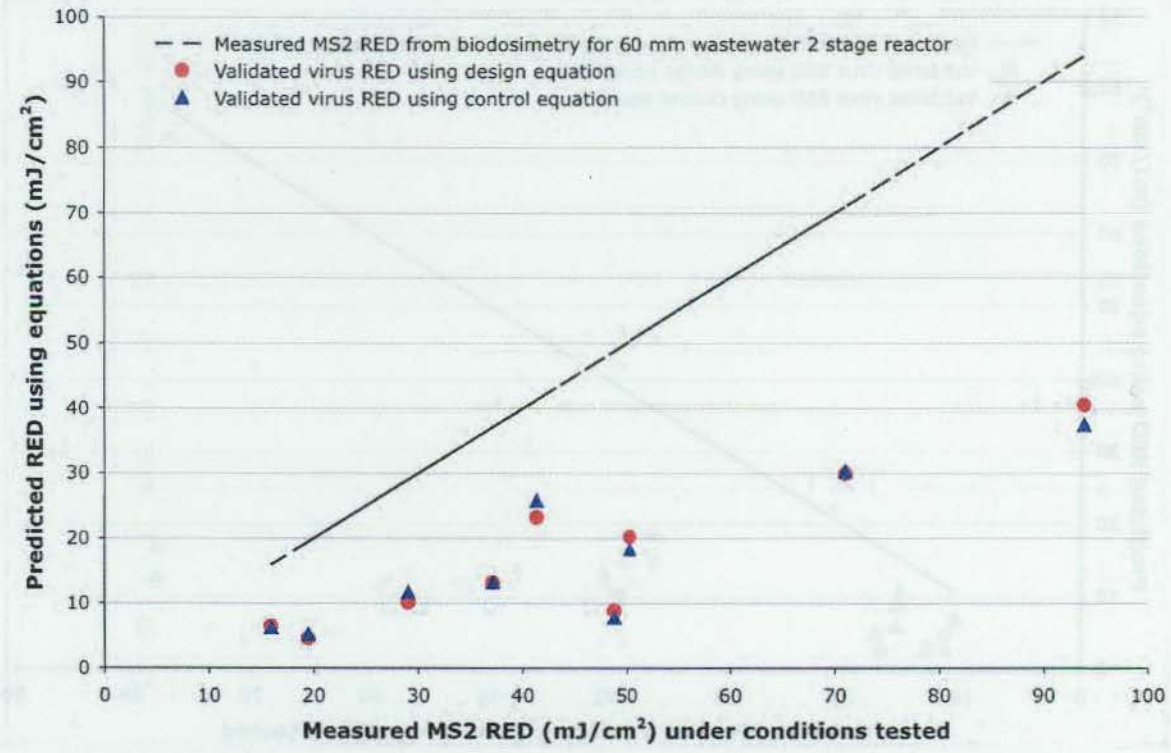


Figure 6-9. Predicted vs observed inactivation for double stage wastewater 60 mm reactor.

6.3. NWRI analysis

6.3.1. NWRI log reductions achieved by the reactors

A summary of the observed log reductions achieved by the reactors is given in a series of tables (Table 6-9 to Table 6-16) for the NWRI method. Log reductions were calculated as the lower 75% confidence limit of the difference between the mean influent and mean effluent MS2 concentrations. It was assumed that log-transformed data were approximately normally distributed. Variances were assumed to be unknown and equal. The t statistic for $\alpha = 0.125$ was multiplied by the standard deviation of the mean difference and subtracted from the mean difference to find the lower 75% confidence limit. For further details of the method used see standard statistical texts, e.g. Walpole and Myers (1993)[1].

6.3.2. NWRI equations to predict the reduction equivalent dose

Equations were derived from the data presented in Section 6.3.1 and combined with the dose-response equations given in Table 5-7. The dose-response equations were explicitly fit only to data where the dose measured was ≥ 20 mJ/cm^2. Therefore, results for which the predicted dose was < 20 mJ/cm^2 were ignored from the regression fitting process. In addition, results for which the influent concentration could not be determined due to the log inactivation being greater than the range of the biodosimetry assay were not able to be used. As a result of these ommissions, of the 9 conditions tested for each reactor, only between 1 and 7 were able to be used in the regression analysis. Where the regression analysis is not informed by sufficient data to provide a log reduction prediction using the equation, the plots of the experimental results can be used instead.

Table 6-8. NWRI RED calculation design equations.

Water type (diameter) [stages]	*RED equation	N	R^2	Significant terms**
Potable (89 mm) [1 stage]	Insufficient data, use data plots rather than equation	3		
Potable (89 mm) [2 stages]	LogRED = 0.965 x log(1/flow) + 3.721 x logUVT - 4.875	6	0.80	All but intercept (p = 0.095)
Potable (60 mm) [1 stage]	LogRED = 0.673 x log(1/flow) + 1.728 x logUVT - 1.525	5	0.99	All but intercept (p = 0.221) and log UVT (p = 0.062)
Potable (60 mm) [2 stages]	LogRED = 0.488 x log(1/flow) + 2.068 x logUVT - 1.914	4	0.97	None, intercept (p = 0.210), log UVT (p = 0.112) and log 1/flow (p = 0.150)
Wastewater (89 mm) [1 stage]	Insufficient data, use data plots rather than equation	1		
Wastewater (89 mm) [2 stages]	Insufficient data, use data plots rather than equation	2		
Wastewater (60 mm) [1 stage]	Insufficient data, use data plots rather than equation	3		
Wastewater (60 mm) [2 stages]	LogRED = 0.680 x log(1/flow) + 1.467 x logUVT - 0.762	7	0.80	All but intercept (p = 0.416)

*Reduction Equivalent UV Dose for MS2.
**The terms that were not significant could be removed from the equation to simplify it.

[1] Walpole RE and Myers RH. 1993. Probability and Statistics for Engineers and Scientists. Fifth Edition. Prentice Hall. Pages 254 to 259.

Table 6-9. MS2 pfu log reduction assigned to reactors using the NWRI method for potable water 89 mm 1 stage reactor.

UVT (%)	Flow (L/s)	UVI (value)	Mean Log influent	Standard deviation of log influent	Mean log effluent	Standard deviation of log effluent	Mean difference (influent less effluent)	Pooled standard deviation	Standard deviation of the mean difference	t-crit (0.125)	Lower 75% confidence bound of mean difference
94.1	8.1	88.5	4.67	0.06	3.87	0.55	0.81	0.39	0.39	1.60	0.18
89.9	4.4	88.5	5.14	0.12	2.69	0.18	2.45	0.16	0.12	1.30	2.30
89.9	2.2	88.5	5.10	0.15	2.81	0.20	2.28	0.18	0.11	1.24	2.14
83.0	8.1	63.3	5.83	0.31	4.89	0.15	0.94	0.24	0.15	1.24	0.75
79.8	4.3	63.3	4.61	0.31	3.90	ND	0.71	ND	ND	1.34	ND
79.8	2.3	63.3	5.14	0.23	3.57	0.50	1.57	0.36	0.28	1.30	1.21
61.2	8.1	33.7	4.76	0.78	4.94	ND	-0.19	ND	ND	1.42	ND
61.2	4.3	33.7	4.98	0.47	4.87	0.40	0.11	0.44	0.28	1.24	-0.23
61.2	2.3	33.7	5.17	0.14	4.16	0.31	1.01	0.24	0.20	1.34	0.74

ND: Not determined due to confluence (too many to count) or too few to count per plate

Table 6-10. MS2 pfu log reduction assigned to reactors using the NWRI method for potable water 89 mm 2 stage reactor.

UVT (%)	Flow (L/s)	UVI (value)	Mean Log influent	Standard deviation of log influent	Mean log effluent	Standard deviation of log effluent	Mean difference (influent less effluent)	Pooled standard deviation	Standard deviation of the mean difference	t-crit (0.125)	Lower 75% confidence bound of mean difference
94.1	8.1	88.5	4.67	0.06	2.44	0.55	2.24	0.45	0.41	1.42	1.65
89.9	4.4	88.5	5.14	0.12	1.28	0.49	3.86	0.36	0.29	1.34	3.47
89.9	2.2	88.5	5.10	0.15	1.00	ND	4.10	ND	ND	1.34	ND
83.0	8.1	63.3	5.83	0.31	3.96	0.60	1.87	0.46	0.31	1.25	1.49
79.8	4.3	63.3	4.61	0.31	2.73	0.07	1.88	0.28	0.23	1.30	1.58
79.8	2.3	63.3	5.14	0.23	1.80	0.68	3.33	0.50	0.36	1.27	2.88
61.2	8.1	33.7	4.76	0.78	4.26	0.36	0.50	0.61	0.43	1.27	-0.04
61.2	4.3	33.7	4.98	0.47	4.22	0.22	0.76	0.38	0.26	1.25	0.43
61.2	2.3	33.7	5.17	0.14	3.33	0.47	1.83	0.37	0.28	1.30	1.46

ND: Not determined due to confluence (too many to count) or too few to count per plate

Table 6-11. MS2 pfu log reduction assigned to reactors using the NWRI method for potable water 60 mm 1 stage reactor.

UVT (%)	Flow (L/s)	UVI (value)	Mean Log influent	Standard deviation of log influent	Mean log effluent	Standard deviation of log effluent	Mean difference (influent less effluent)	Pooled standard deviation	Standard deviation of the mean difference	t-crit (0.125)	Lower 75% confidence bound of mean difference
89.9	4.2	102.0	4.22	0.11	2.10	0.56	2.13	0.40	0.40	1.60	1.48
94.1	2.2	102.0	4.83	ND	2.26	ND	2.57	ND	ND	ND	ND
89.9	1.1	102.0	4.23	0.34	1.00	0.00	3.23	0.29	0.25	1.34	2.89
79.8	4.2	89.2	4.91	0.44	3.19	0.70	1.72	0.58	0.37	1.24	1.26
83.0	2.2	89.2	5.93	0.28	3.99	0.28	1.94	0.28	0.19	1.25	1.70
79.8	1.2	89.2	4.88	0.30	2.18	0.28	2.69	0.29	0.21	1.27	2.43
61.2	4.2	76.6	5.01	0.35	4.58	0.47	0.43	0.39	0.29	1.27	0.07
61.2	2.3	76.6	5.39	0.07	4.72	0.22	0.66	0.16	0.11	1.25	0.53
61.2	1.2	76.6	5.19	0.18	3.61	0.79	1.59	0.54	0.36	1.25	1.14

ND: Not determined due to confluence (too many to count) or too few to count per plate

Table 6-12. MS2 pfu log reduction assigned to reactors using the NWRI method for potable water 60 mm 2 stage reactor.

UVT (%)	Flow (L/s)	UVI (value)	Mean Log influent	Standard deviation of log influent	Mean log effluent	Standard deviation of log effluent	Mean difference (influent less effluent)	Pooled standard deviation	Standard deviation of the mean difference	t-crit (0.125)	Lower 75% confidence bound of mean difference
89.9	4.2	102.0	4.22	0.11	ND	ND	ND	ND	ND	#NUM!	ND
94.1	2.2	102.0	4.83	ND	ND	ND	ND	ND	ND	#NUM!	ND
89.9	1.1	102.0	4.23	0.34	ND	ND	ND	ND	ND	1.60	ND
79.8	4.2	89.2	4.91	0.44	2.16	0.59	2.75	0.50	0.36	1.27	2.29
83.0	2.2	89.2	5.93	0.28	2.33	0.16	3.61	0.24	0.18	1.30	3.37
79.8	1.2	89.2	4.88	0.30	ND	ND	ND	ND	ND	1.60	ND
61.2	4.2	76.6	5.01	0.35	4.13	0.42	0.88	0.38	0.24	1.24	0.58
61.2	2.3	76.6	5.39	0.07	3.26	0.22	2.13	0.16	0.10	1.25	1.99
61.2	1.2	76.6	5.19	0.18	2.65	0.07	2.54	0.14	0.09	1.24	2.43

ND: Not determined due to confluence (too many to count) or too few to count per plate

Table 6-13. MS2 pfu log reduction assigned to reactors using the NWRI method for wastewater 89 mm 1 stage reactor.

UVT (%)	Flow (L/s)	UVI (value)	Mean Log influent	Standard deviation of log influent	Mean log effluent	Standard deviation of log effluent	Mean difference (influent less effluent)	Pooled standard deviation	Standard deviation of the mean difference	t-crit (0.125)	Lower 75% confidence bound of mean difference
62.5	8.2	36.1	4.62	0.19	4.26	0.22	0.36	0.21	0.16	1.30	0.15
62.5	4.4	36.1	4.34	0.29	4.11	0.27	0.22	0.28	0.19	1.25	-0.01
62.5	2.1	36.1	4.47	0.41	1.90	0.96	2.58	0.74	0.60	1.34	1.76
49.3	8.1	23.5	4.96	0.32	4.94	0.21	0.02	0.27	0.19	1.27	-0.22
51.0	4.4	23.5	4.86	0.38	4.65	0.17	0.21	0.29	0.19	1.24	-0.02
51.0	2.3	23.5	4.40	0.18	3.55	0.64	0.85	0.47	0.33	1.27	0.42
40.9	8.1	17.6	5.10	0.28	4.92	0.27	0.18	0.28	0.19	1.25	-0.06
39.1	4.3	17.6	5.28	0.08	4.56	0.36	0.72	0.33	0.27	1.30	0.37
39.1	2.2	17.6	4.89	0.26	4.72	0.31	0.17	0.28	0.19	1.25	-0.07

ND: Not determined due to confluence (too many to count) or too few to count per plate

Table 6-14. MS2 pfu log reduction assigned to reactors using the NWRI method for wastewater 89 mm 2 stage reactor.

UVT (%)	Flow (L/s)	UVI (value)	Mean Log influent	Standard deviation of log influent	Mean log effluent	Standard deviation of log effluent	Mean difference (influent less effluent)	Pooled standard deviation	Standard deviation of the mean difference	t-crit (0.125)	Lower 75% confidence bound of mean difference
62.5	8.2	36.1	4.62	0.19	4.03	0.29	0.58	0.26	0.19	1.27	0.34
62.5	4.4	36.1	4.34	0.29	3.86	0.52	0.48	0.44	0.29	1.25	0.12
62.5	2.1	36.1	4.47	0.41	1.66	0.64	2.82	0.54	0.44	1.34	2.22
49.3	8.1	23.5	4.96	0.32	4.50	0.23	0.46	0.27	0.18	1.25	0.24
51.0	4.4	23.5	4.86	0.38	4.40	0.46	0.46	0.42	0.27	1.24	0.13
51.0	2.3	23.5	4.40	0.18	2.70	0.22	1.71	0.20	0.14	1.25	1.53
40.9	8.1	17.6	5.10	0.28	4.36	0.29	0.73	0.28	0.18	1.24	0.51
39.1	4.3	17.6	5.28	0.08	4.35	0.44	0.93	0.39	0.33	1.30	0.50
39.1	2.2	17.6	4.89	0.26	4.09	0.18	0.80	0.24	0.17	1.27	0.58

ND: Not determined due to confluence (too many to count) or too few to count per plate

Table 6-15. MS2 pfu log reduction assigned to reactors using the NWRI method for wastewater 60 mm 1 stage reactor.

UVT (%)	Flow (L/s)	UVI (value)	Mean Log influent	Standard deviation of log influent	Mean log effluent	Standard deviation of log effluent	Mean difference (influent less effluent)	Pooled standard deviation	Standard deviation of the mean difference	t-crit (0.125)	Lower 75% confidence bound of mean difference
62.5	4.2	77.6	4.42	0.10	3.73	0.48	0.68	0.33	0.22	1.25	0.41
62.5	2.1	77.6	4.15	0.29	2.85	0.16	1.30	0.22	0.15	1.25	1.11
62.5	1.1	77.6	4.54	0.18	2.86	0.69	1.68	0.51	0.32	1.24	1.28
51.0	4.2	72.2	4.79	0.24	4.64	0.43	0.15	0.36	0.24	1.25	-0.15
49.3	2.3	72.2	4.57	0.36	3.41	1.05	1.17	0.78	0.49	1.24	0.55
49.3	1.1	72.2	4.46	0.54	2.84	0.19	1.63	0.38	0.25	1.25	1.31
40.9	4.1	69.9	4.96	0.12	4.63	0.44	0.33	0.30	0.20	1.25	0.08
39.1	2.2	69.9	5.09	0.19	4.72	0.11	0.37	0.18	0.15	1.30	0.17
40.9	1.2	69.9	4.74	0.22	4.32	0.31	0.42	0.26	0.20	1.30	0.16

ND: Not determined due to confluence (too many to count) or too few to count per plate

Table 6-16. MS2 pfu log reduction assigned to reactors using the NWRI method for wastewater 60 mm 2 stage reactor.

UVT (%)	Flow (L/s)	UVI (value)	Mean Log influent	Standard deviation of log influent	Mean log effluent	Standard deviation of log effluent	Mean difference (influent less effluent)	Pooled standard deviation	Standard deviation of the mean difference	t-crit (0.125)	Lower 75% confidence bound of mean difference
62.5	4.2	77.6	4.42	0.10	2.67	0.11	1.75	0.10	0.08	1.27	1.65
62.5	2.1	77.6	4.15	0.29	2.33	0.35	1.81	0.32	0.23	1.27	1.53
62.5	1.1	77.6	4.54	0.18	1.23	0.40	3.31	0.28	0.20	1.27	3.05
51.0	4.2	72.2	4.79	0.24	4.13	0.66	0.66	0.52	0.35	1.25	0.21
49.3	2.3	72.2	4.57	0.36	2.96	0.31	1.62	0.34	0.21	1.24	1.35
49.3	1.1	72.2	4.46	0.54	1.30	0.66	3.17	0.61	0.41	1.25	2.65
40.9	4.1	69.9	4.96	0.12	4.12	0.43	0.84	0.31	0.20	1.24	0.60
39.1	2.2	69.9	5.09	0.19	3.80	0.14	1.29	0.19	0.15	1.30	1.09
40.9	1.2	69.9	4.74	0.22	2.95	0.08	1.79	0.17	0.12	1.27	1.64

ND: Not determined due to confluence (too many to count) or too few to count per plate

6.3.3. NWRI design curves

A worksheet was set up to allow prediction of reduction equivalent dose using the NWRI method based on the equations given in Table 6-8. An example of how this worksheet would be used is given in Figure 6-10. The design curves are more conservative than those illustrated for the UVDGM method (Figure 6-1). However, the design curves under the UVDGM method would be subjected to further correction using a Validation Factor for the assignment of log credits. Under NWRI, the safety factors are included in the assignment of reactor log reduction values (Section 6.3.1), prior to the development of the design equations. Figure 6-10 can be read directly to inform NWRI log reduction credits for viruses.

6.3.4. Visualising the NWRI output

Illustrated in Figure 6-11 to Figure 6-14 are a series of plots that show a comparison of the mean reduction equivalent dose measured during the biodosimetry, along with the lower 75% confidence limit for the same value (see Section 6.3.1 for derivation), and the calculated dose using the regression equations fitted to the lower 75% confidence limits (see Table 6-8 for the equations used).

Following the four regression plots, empirical plots of the observed and lower 75% confidence bounds of the observed data are given to provide look up plots to use in lieu of regression equations.

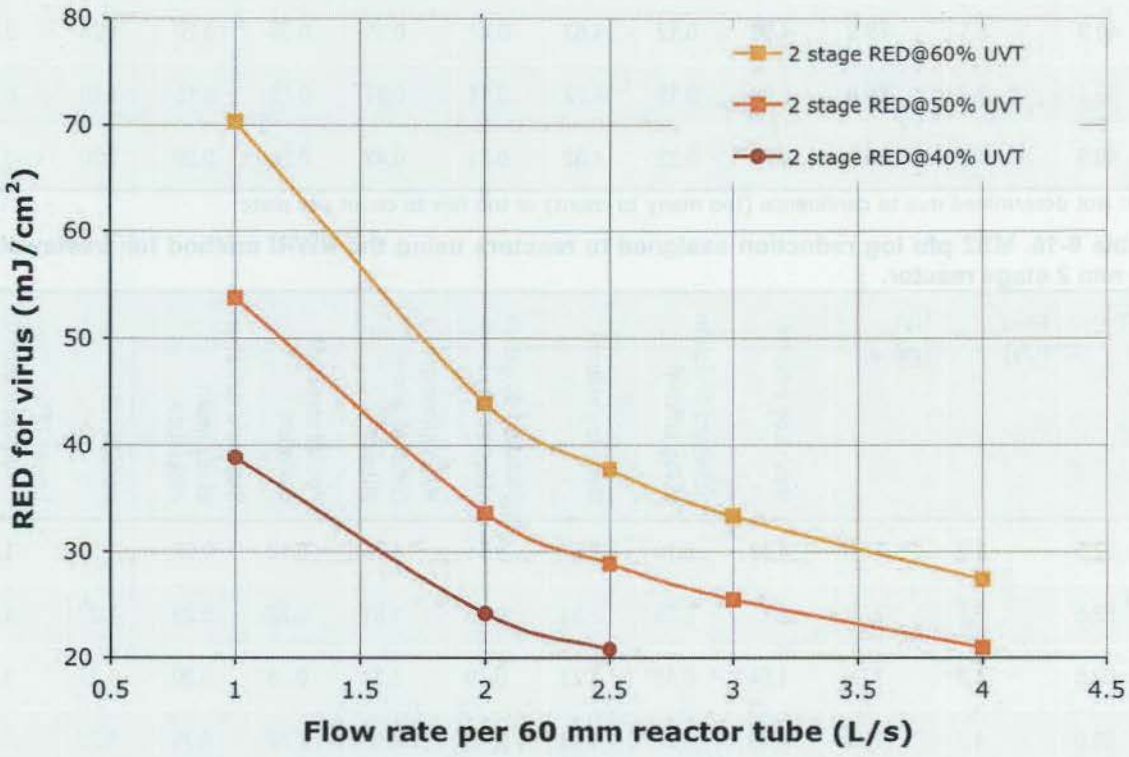


Figure 6-10. Example of design curve for 60 mm wastewater 2 stage reactor (NWRI method).

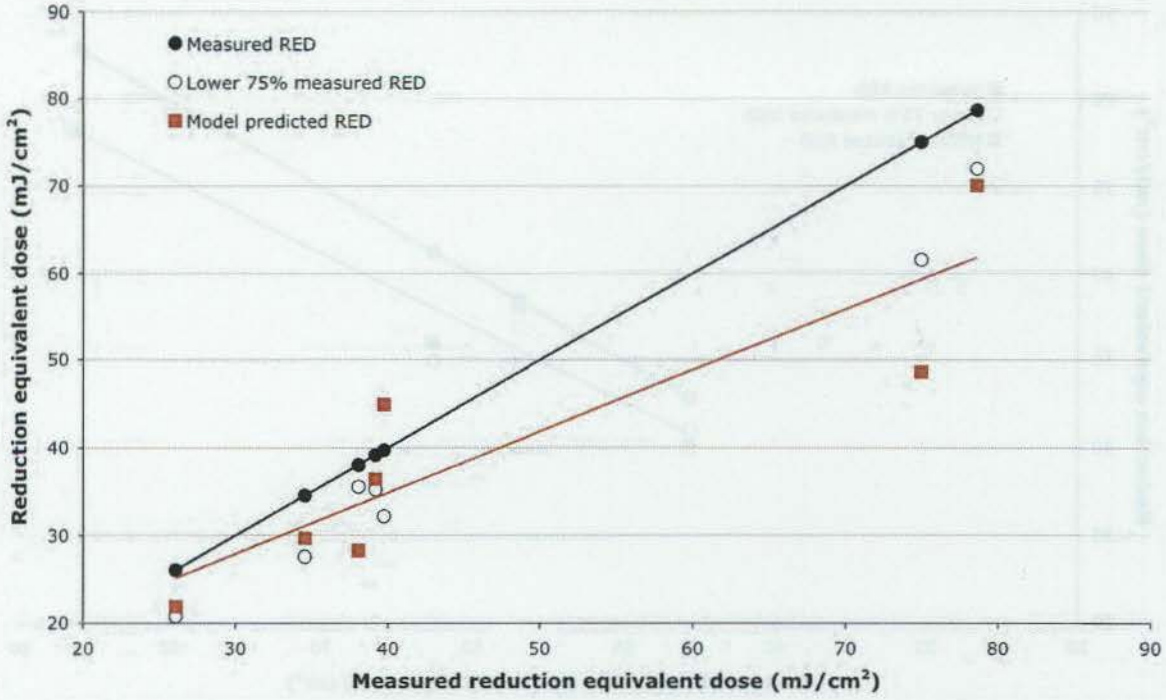


Figure 6-11. Comparison of the model-predicted with the observed, and lower 75% confidence limit of the observed, RED for the 60 mm wastewater 2 stage reactor (NWRI method).

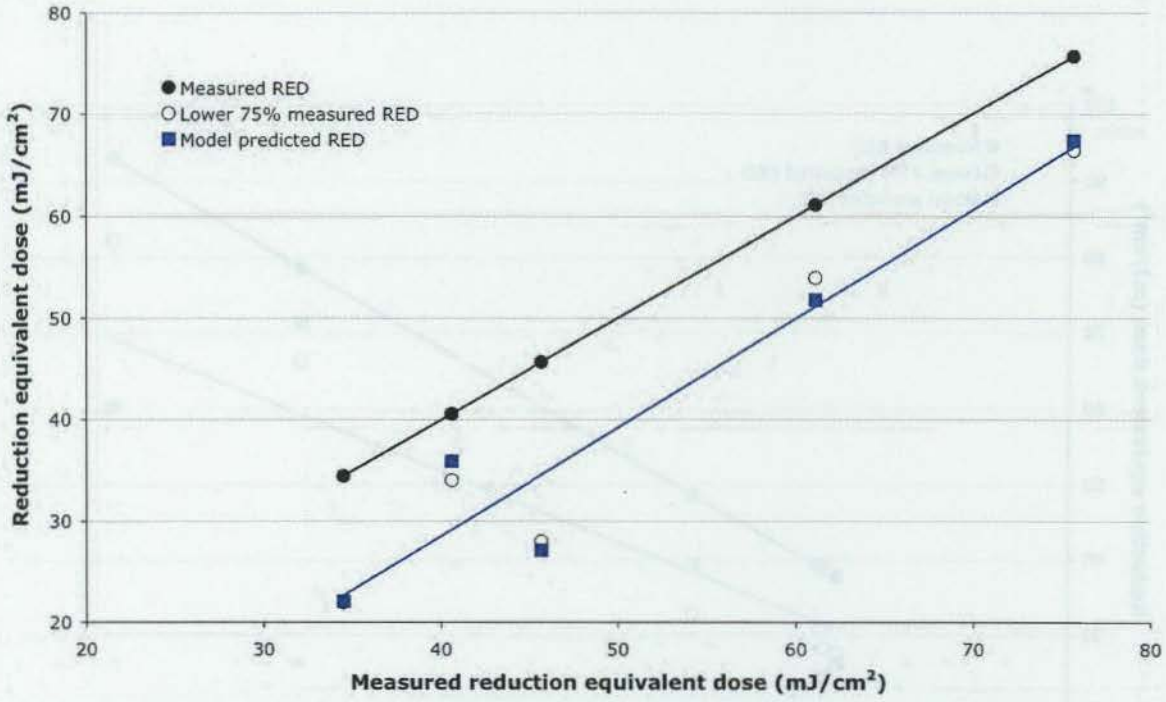


Figure 6-12. Comparison of the model-predicted with the observed, and lower 75% confidence limit of the observed, RED for the 60 mm potable water 1 stage reactor (NWRI method).

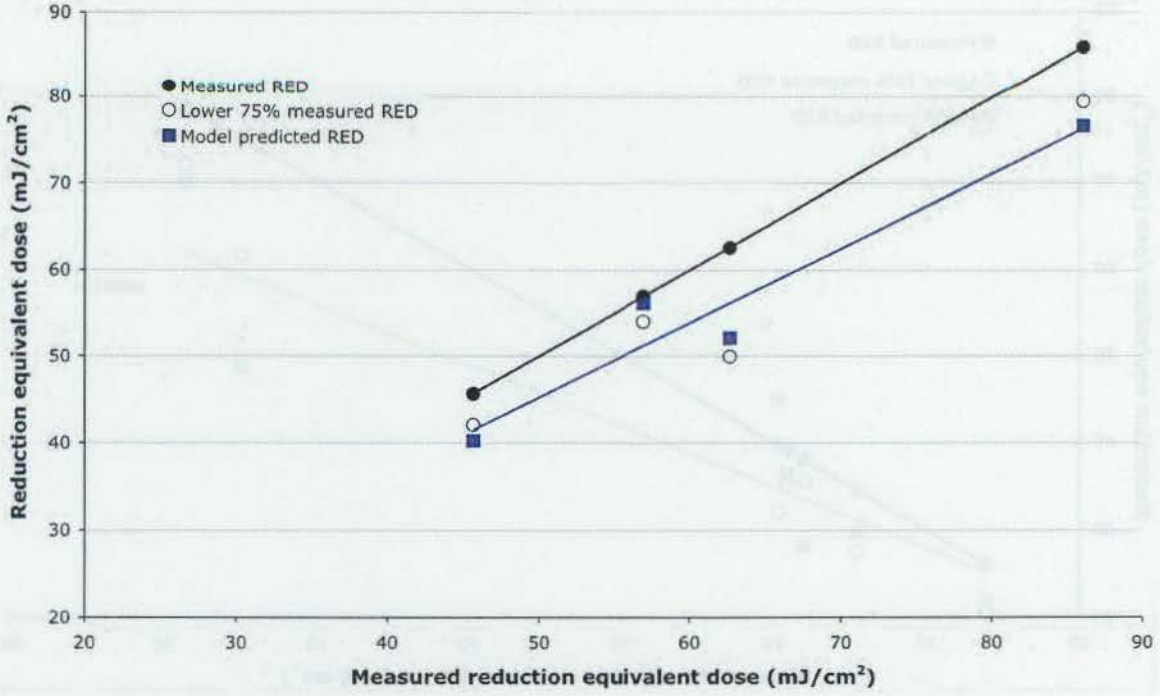


Figure 6-13. Comparison of the model-predicted with the observed, and lower 75% confidence limit of the observed, RED for the 60 mm potable water 2 stage reactor (NWRI method).

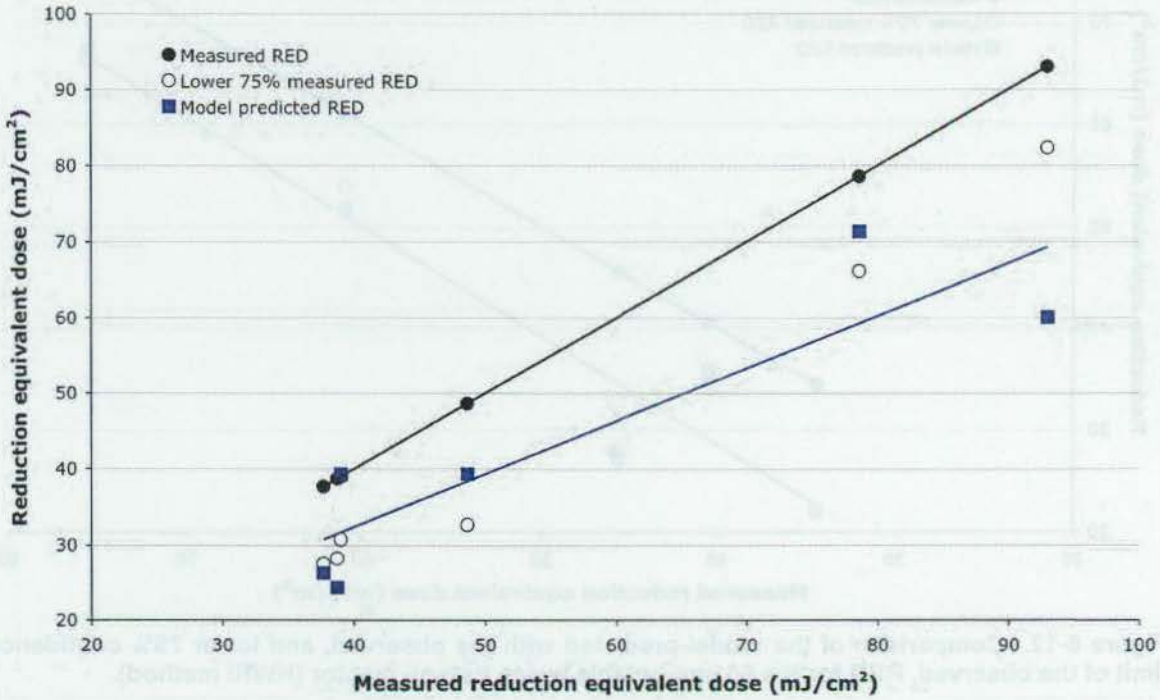


Figure 6-14. Comparison of the model-predicted with the observed, and lower 75% confidence limit of the observed, RED for the 89 mm potable water 2 stage reactor (NWRI method).

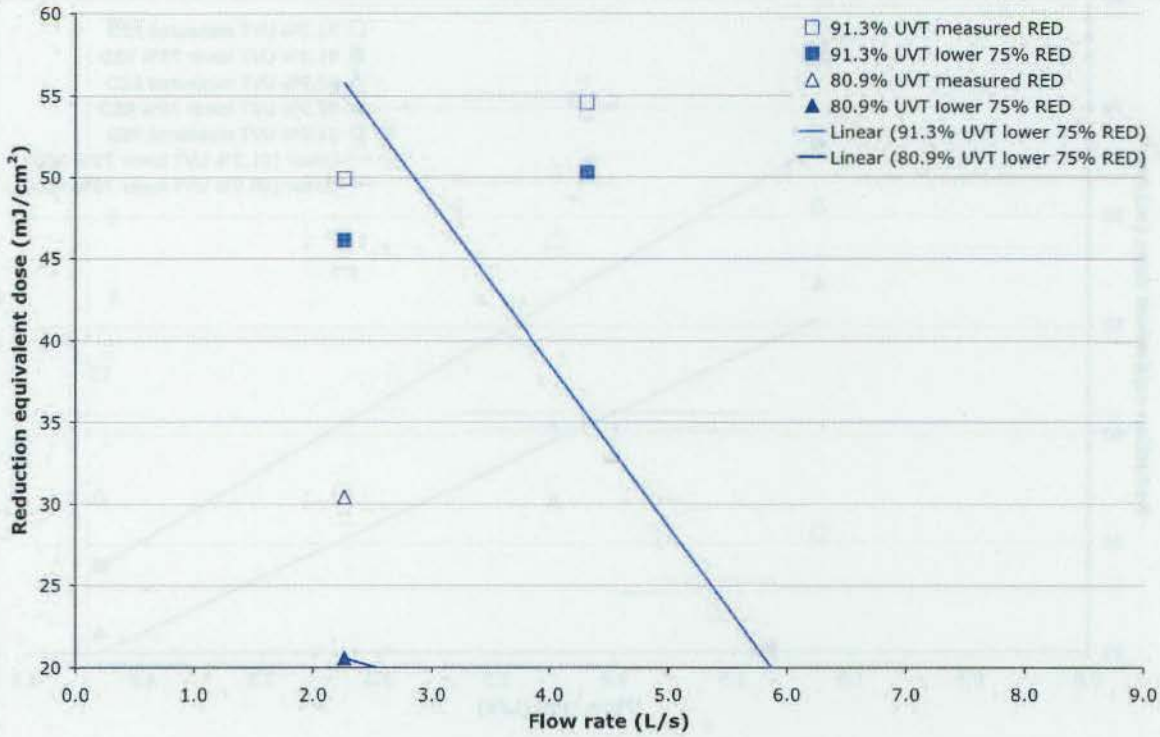


Figure 6-15. Illustration of the observed and lower 75% confidence limit RED for the 89 mm potable water 1 stage reactor (NWRI method).

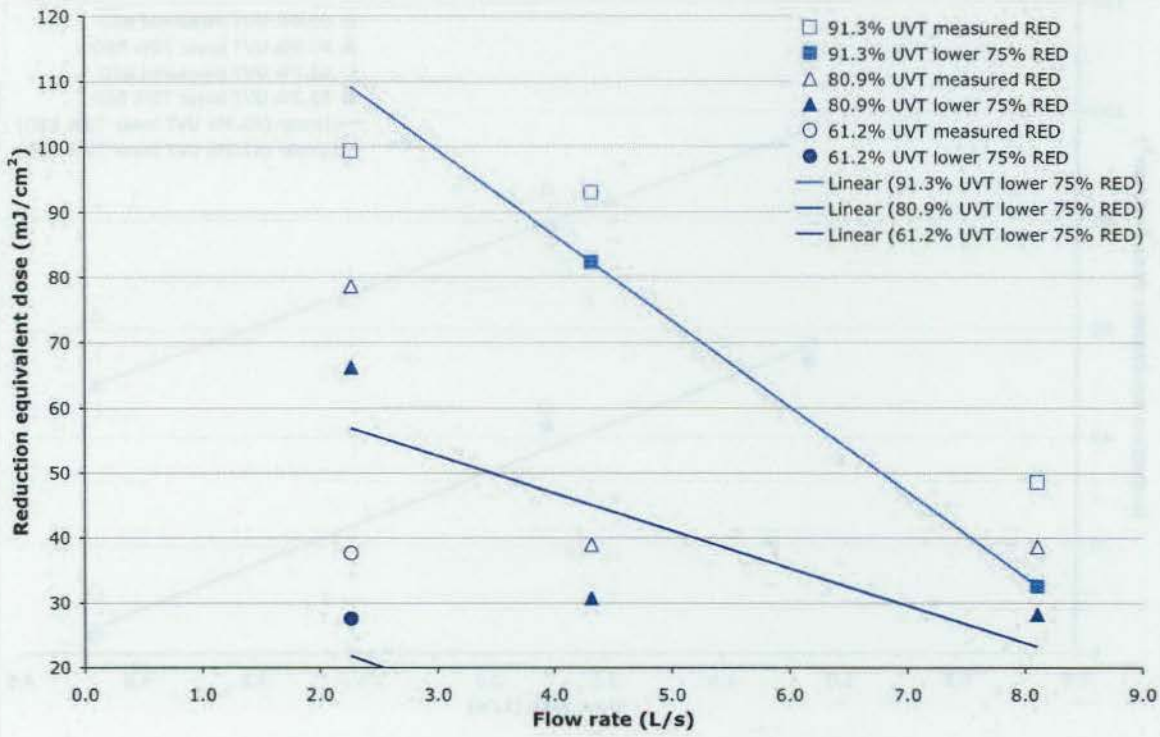


Figure 6-16. Illustration of the observed and lower 75% confidence limit RED for the 89 mm potable water 2 stage reactor (NWRI method).

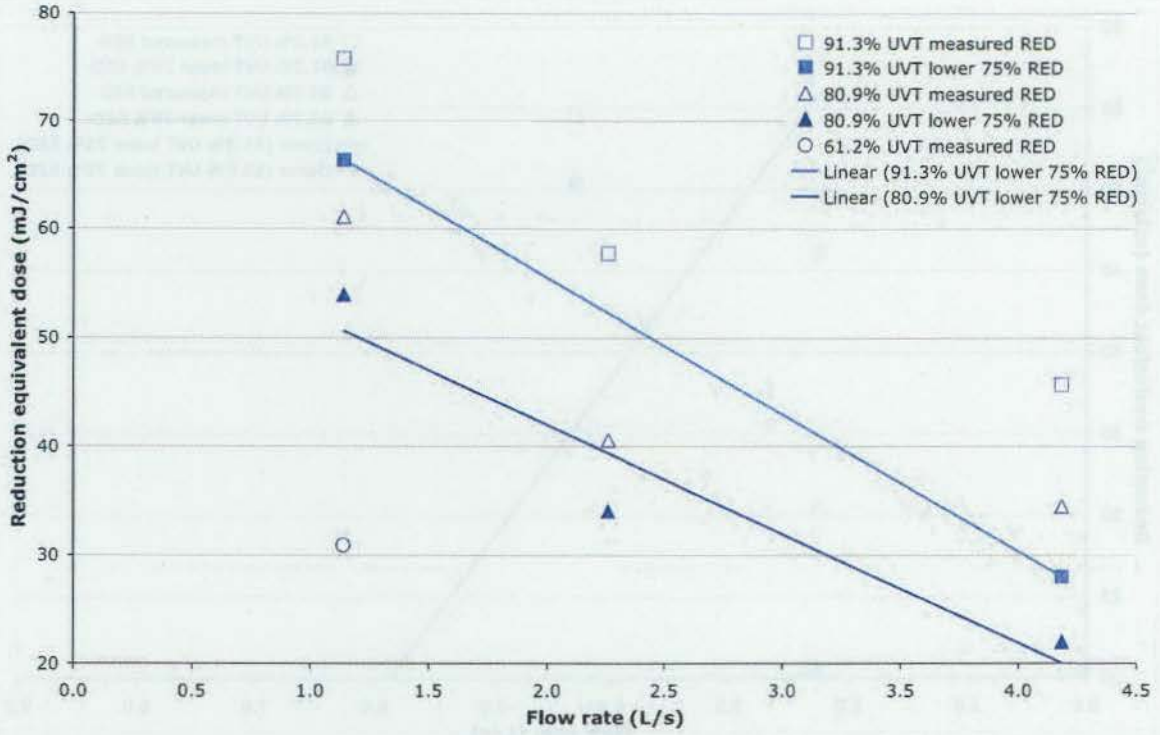


Figure 6-17. Illustration of the observed and lower 75% confidence limit RED for the 60 mm potable water 1 stage reactor (NWRI method).

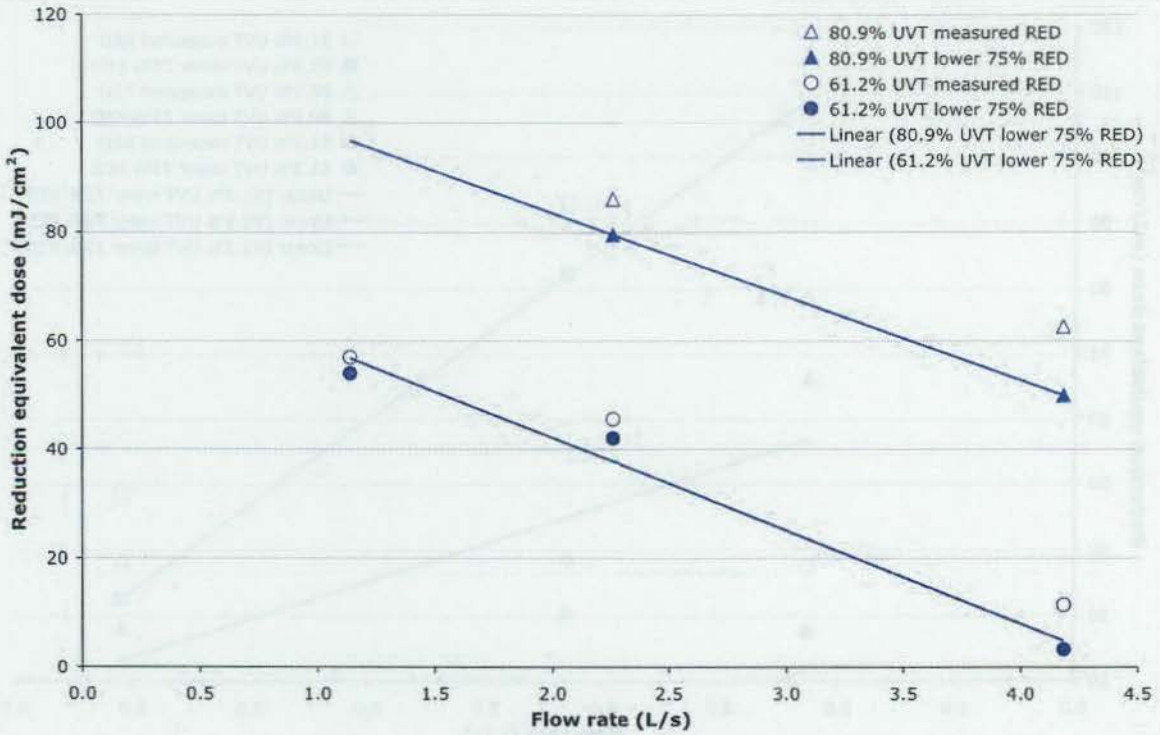


Figure 6-18. Illustration of the observed and lower 75% confidence limit RED for the 60 mm potable water 2 stage reactor (NWRI method).

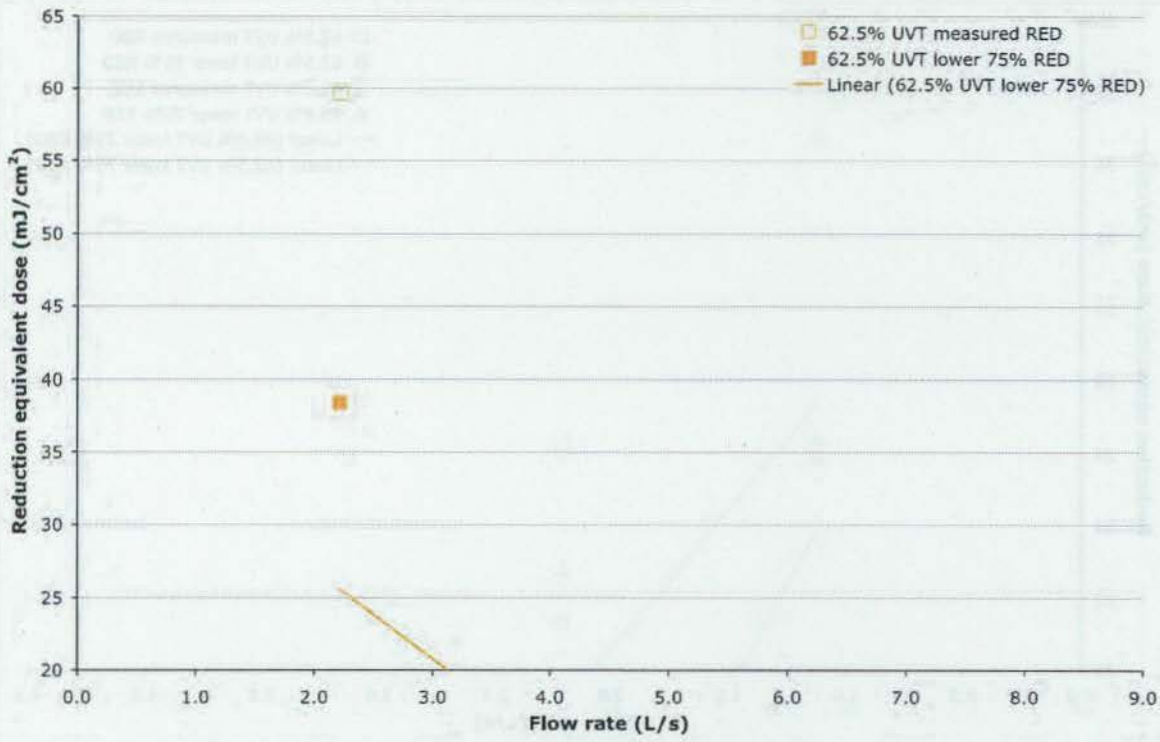


Figure 6-19. Illustration of the observed and lower 75% confidence limit RED for the 89 mm wastewater 1 stage reactor (NWRI method).

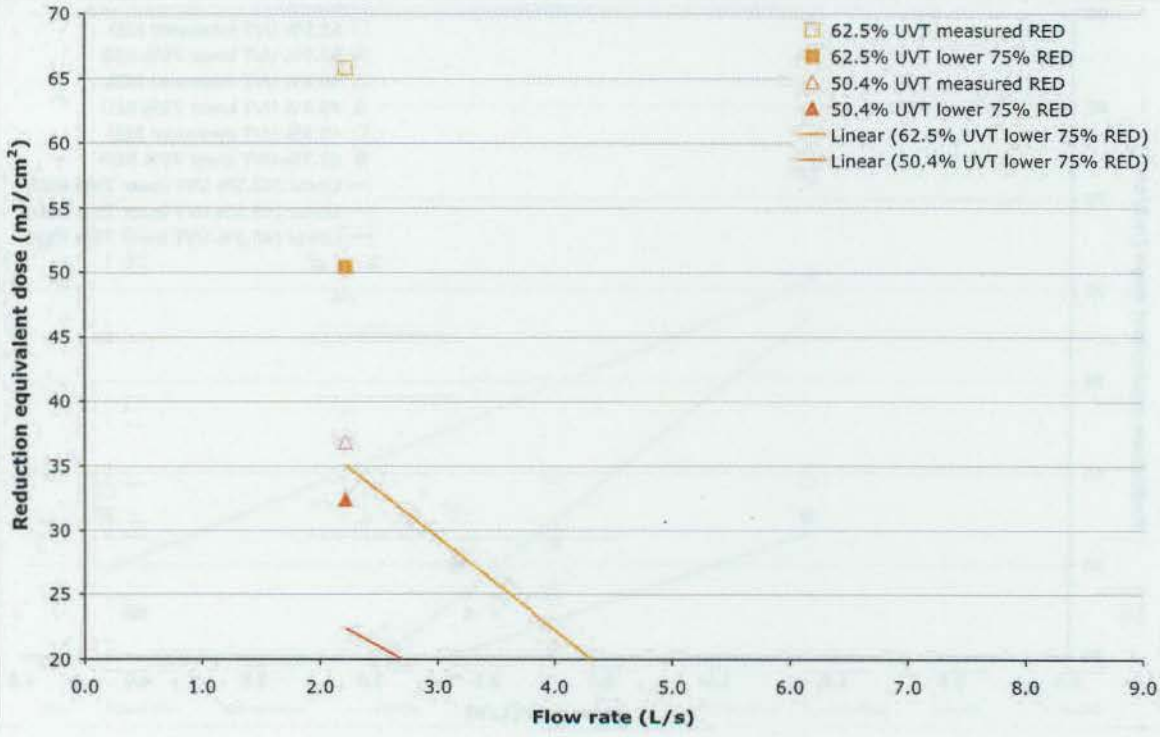


Figure 6-20. Illustration of the observed and lower 75% confidence limit RED for the 89 mm wastewater 2 stage reactor (NWRI method).

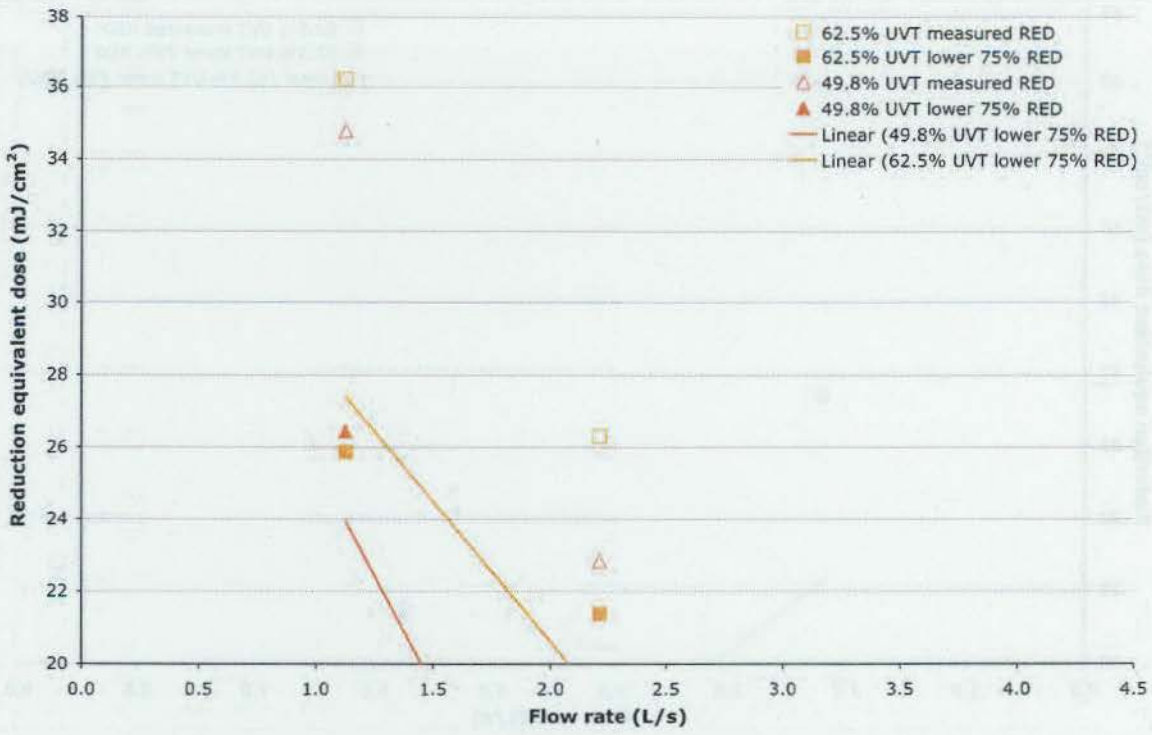


Figure 6-21. Illustration of the observed and lower 75% confidence limit RED for the 60 mm wastewater 1 stage reactor (NWRI method).

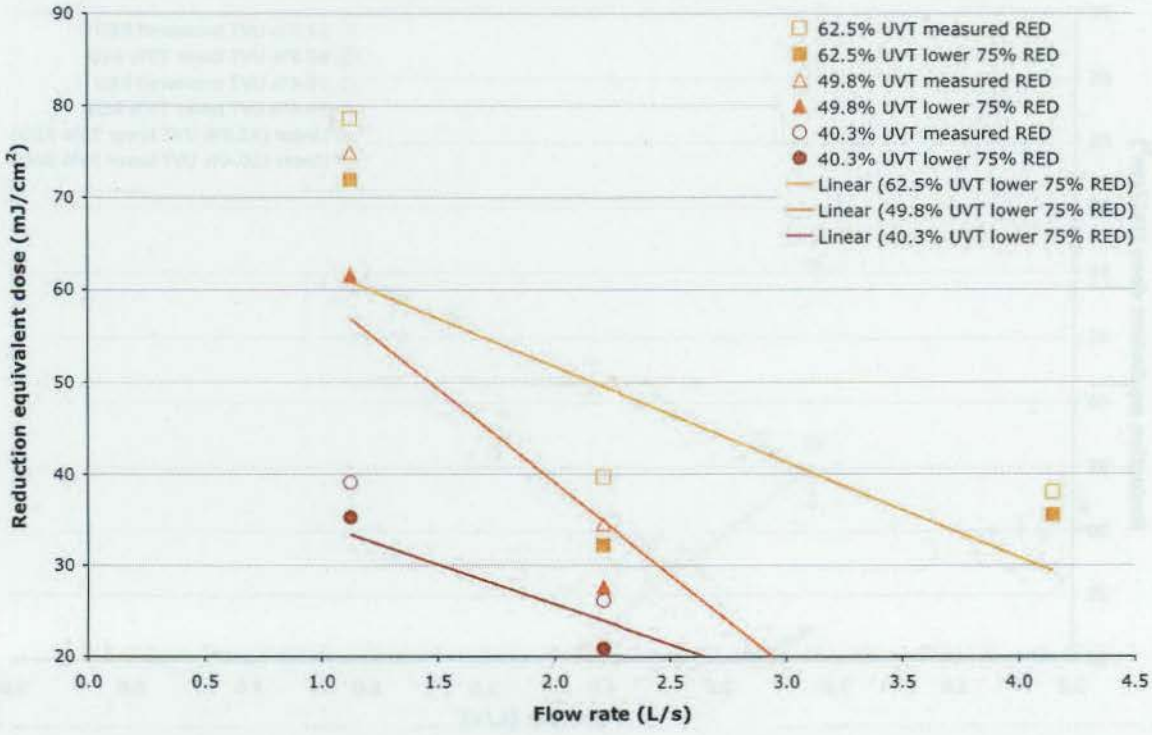


Figure 6-22. Illustration of the observed and lower 75% confidence limit RED for the 60 mm wastewater 2 stage reactor (NWRI method).

7. Quality Assurance and Quality Control

7.1. Measurement uncertainties

The uncertainties assigned to each measurement are given in Table 7-1 along with a summary of the derivation of those uncertainties and a comparison with the default criteria given in the UVDGM.

Table 7-1. Uncertainties.

Item	Default Criterion	Assigned value	Details of derivation and application
Flow meter	< 5%	0.1%	ABB Australian Pty Ltd calibration certificates for tests carried out at 1.5, 7.5 and 15 L/s in June 2007 for each meter. Assigned value rounded up from worst observed value from all runs (0.08%).
UV spectrophotometer	< 10%	2%	Supplied by AWQC.
Duty UV sensors (US)	< 10%	10.36%	Four UV sensors were used. The greatest deviation of any one (representing the duty sensor) from the other three (representing the reference sensors) was found to be 10.36%. The assigned value was included in the validation factor.
Radiometer	< 8%	7.5%	Supplied by AWQC. Type 2 uncertainty ± 6.5% + NIST uncertainty of 1% (200-400 nm), based on International Light calibration report dated July 2003.
Depth of suspension	≤ 10%	2%	Supplied by AWQC.
Incidence irradiance	≤ 8%	6.5%	Supplied by AWQC.
Petri Factor	≤ 5%	2.5%	Supplied by AWQC.
L/(d + L)	≤ 1%	0.3%	Supplied by AWQC.
Time	≤ 5%	2%	Supplied by AWQC.
(1-10-ad)/ad	≤ 5%	4% (ad < 0.1)	Supplied by AWQC.
Uncertainty in dose-response (UDR) potable water	≤ 30%	100.4%	Calculated using linear regression from the data supplied by AWQC for water at 90, 80 and 60% UVT and combined for all three UVT levels. The assigned value was included in the validation factor.
Uncertainty in dose-response (UDR) wastewater	≤ 30%	67.1%	Calculated using linear regression from the data supplied by AWQC for wastewater at 60% UVT. The assigned value was included in the validation factor.
		31.8%	Calculated using linear regression from the data supplied by AWQC for wastewater at 50% UVT. The assigned value was included in the validation factor.
		100.9%	Calculated using linear regression from the data supplied by AWQC for wastewater at 40% UVT. The assigned value was included in the validation factor.

8. Case study

8.1. Introduction

The validation testing involved multiple tube diameters, water types, stages, flow rates and UVT levels. This report applied both the UVDGM and NWRI methods to provide a summary of the validation methodology for these reactors. However, specific reactor designs in their specific contexts are likely to have slightly different design features. The information contained within this report can be used to provide estimated doses and pathogen inactivation credits for any reactor design within the validated range. To illustrate how specific reactor design validation is undertaken, two case studies are given in this section of the report. The first case study adopts the simpler NWRI methodology to estimate a dose for a reactor. The second applies the more complex UVDGM methodology to calculate a log reduction credit.

8.2. Information requirements

The following information is required to apply the validation program results to any specific design:

- The water type for the reactor, e.g. secondary treated wastewater, conventionally treated potable water or tertiary treated wastewater.
- Flow rate per tube for the tube in the reactor with the fastest hydraulic flow rate. For multiple-tube reactors, computational fluid dynamic (CFD) modelling and/or empirical on-site flow testing is required to determine this flow rate. Note that the flow range within this fastest tube must be within the range validated. Interpolation between upper and lower flow rate ranges is appropriate, but extrapolation beyond those ranges is not. For flow rates lower than those validated, an assumption of the lowest measured flow rate must be applied. The flow rates higher than those validated, the validation is void.
- The range of UVT of interest. Note that the range of UVT must be within the range validated. Interpolation between upper and lower UVT ranges is appropriate, but extrapolation beyond those ranges is not. For UVT ranges higher than those validated, an assumption of the highest measured flow rate must be applied. For UVT ranges lower than those validated, the validation is void.
- Number of reactor stages in series. The validation was run for both one and two stages but, in theory, any number of stages can be placed in series by adding the doses for the single or double stage experiments.
- The reactor tube diameter. This validation only applies to 60 mm ø and 89 mm ø reactors. Other reactor diameters are not covered by this validation.
- The arrangement of the reactor. This validation only applies to the validated reactor arrangements with respect to lamp positioning, tube and lamp spacing and reactor hydraulics. Due to the conservative nature of the test rig, using the internal black plastic coating, reactors with multiple tubes can be arranged in parallel provided flow rate effects are taken into consideration.
- The lamp age and lamp operating conditions required. The validation was based on having all lamps on with average lamp age of > 8,000 hours, therefore, average lamp age in the intended application must be ≤ 8,000 hours and all lamps must be on to be within the validated range.
- The information required by the customer. The information might include the reduction equivalent dose demonstrated, and/or the validated pathogen log credit.
- The guideline or regulation to be applied. The relevant reference document may be the UVDGM 2006, UVDGM 2003 (draft), NWRI or some other requirement.

8.3. NWRI Case Study

8.3.1. NWRI case study information

For this case study, a customer has sought information on the ability of a UV reactor to disinfect wastewater. The customer has requested that a reactor be supplied to provide a validated dose of ≥ 100 mJ/cm^2 for wastewater of UVT ≥ 50% against the NWRI guidelines for reuse to treat a flow rate of ≤ 33 L/s. This case study illustrates how the required maximum flow rate per flow tube is calculated and then used to determine the optimum full-scale reactor design. The case study information is given in Table 8-1 of this report.

Table 8-1. Information provided for the NWRI case study reactor.

Item	Case study	Within allowable range?	Reference
Water type	Wastewater	Yes	Table 4-1 of this report
Flow rate in flow tube with highest flow rate	To be determined in this case study for specification with total flow of ≤ 33 L/s required.	Between 1 to 4 L/s	Table 4-1 of this report
UVT	≥ 50%	Yes, for wastewater	Table 4-1 of this report
Redundancy required	Continuous	Yes, if a backup stage is included in the event of lamp failure	Table 4-1 of this report
Flow tube diameter	60 mm	Yes	Table 4-1 of this report
Reactor arrangement	As per the validated reactor	Yes	Section 3 of this report
Lamp arrangement	As per the validated reactor; average lamp life to be ≤ 5,000 hours	Yes	Table 4-1 of this report
Information required	Design capable of 100 mJ/cm^2 validated dose against NWRI guidance.	Yes	Section 6.3 of this report
Guideline required	NWRI	Yes	Section 6.3 of this report

8.3.2. NWRI reactor design

A simple worksheet is set up that uses the appropriate reactor design equation. In this case the NWRI section of the report is used rather than the USEPA section. The equivalent approach would apply for the use of the USEPA section.

The relevant equation in this case is that associated with a 60 mm ø wastewater reactor. The equation chosen is: Log (RED) = 0.680 x log (1/flow) + 1.467 x log (UVT) - 0.762. This equation is given in Table 6-8 of this report. A worksheet is then set up and used to find the flow rates that give the required dose for the four, six and eight stage reactor designs. The results of the use of the equation for this purpose are given in Table 8-2 of this report.

Based on these results, options can be costed to supply a four, six or eight stage reactor with the documented per tube flow rates.

For this case study, to fit within the footprint of the available space, and to take advantage of available CFD modelling data on flow rates per tube, it is decided to use a reactor design with twenty parallel

tubes per stage. For such a reactor, CFD modelling shows that the flow rate in the fastest tube is the average flow rate per tube multiplied by 1.2. For the desired 33 L/s flow rate, the average flow rate through each of 20 tubes is 1.7 L/s and the flow rate through the fastest tube is 2.0 L/s. Therefore, based on Table 8-2 of this report, the six-stage reactor is chosen.

An additional two stages are installed to allow for possible lamp failure or maintenance activities in one or more of the upstream stages. Upon lamp failure or other activities that cause lamps to be off, the affected stage is shut down once one of the additional stage has warmed up. Supplying two additional stages further increases the reliability of continuity of supply.

In summary, the chosen design to give a 100 mJ/cm^2 validated UV dose for wastewater of UVT ≥50% treating a flow rate of ≤ 33 L/s includes six stages in series with 20 parallel 60 mm ø flow tubes per stage. Two additional stages are installed to allow for a high level of supply continuity.

Table 8-2. Results of NWRI case study design.

Number of stages	UVT	Validated RED (NWRI) mJ/cm^2	Maximum flow rate per tube for the fastest tube (L/s)
4	50%	107.7	1.0
6	50%	100.8	2.0
8	50%	100.2	3.0

8.4. USEPA Case Study

8.4.1. USEPA case study information

For this case study, a customer has sought information on the ability of a UV reactor to disinfect drinking water. The customer has requested that a reactor be supplied to provide a validated dose of ≥ 50 mJ/cm^2 for wastewater of UVT ≥ 90% against the USEPA UVDGM for potable water use to treat a flow rate of ≤ 130 L/s. The customer has sought a *Cryptosporidium* log credit of 2.5 against the UVDGM. This case study illustrates how the required maximum flow rate per flow tube and log credit is calculated and then used to determine the optimum full-scale reactor design. The case study information is given in Table 8-3 of this report.

8.4.2. USEPA reactor design

A simple worksheet is set up that uses the appropriate reactor design equation. In this case the USEPA section of the report is used rather than the NWRI section. The equivalent approach would apply for the use of the NWRI section.

The relevant equation in this case is that associated with a 89 mm ø potable water reactor. The equation chosen is: LogRED = 0.634 x log(1/flow) + 0.968 x logUVT. This equation is given in Table 6-4 of this report. A worksheet is then set up and used to find the flow rates that give the required dose for the one, two and three stage reactor designs. The results of the use of the equation for this purpose are given in Table 8-4 of this report.

To find the flow rates that give the required log reduction credit, the UV sensitivity of the challenge microorganism MS2 is first found from Table 5-4 of this report. The result is 23.2 mJ/cm^2 per log inactivation. Appendix G of the UVDGM, at page G-5, then provides the appropriate RED bias for 2.5 log inactivation of *Cryptosporidium*. The result is 1.87. This value is incorporated into the validation factor for *Cryptosporidium*. In addition, the U_{DR} and U_{IN} factors are found from Table 5-5 and Table 6-6 of this report, respectively, to give the U_{VAL} term. In this case U_{DR} is 100.4% and U_{IN} is 114.6% leading to a U_{VAL} of 152.4%. When incorporating the RED bias this leads to the *Cryptosporidium* validation factors shown in Table 8-4 of this report.

Based on these results, options can be costed to supply a one or two stage reactor with the documented per tube flow rates.

For this case study, to fit within the footprint of the available space, and to take advantage of available CFD modelling data on flow rates per tube, it is decided to use a reactor design with twenty parallel tubes per stage. For such a reactor, CFD modelling shows that the flow rate in the fastest tube is the average flow rate per tube multiplied by 1.2. For the desired 130 L/s flow rate, the average flow rate through 20 tubes is 6.5 L/s and the flow rate through the fastest tube is 7.9 L/s. Therefore, based on Table 8-4 of this report, the two-stage reactor is chosen.

Table 8-3. Information provided for the USEPA case study reactor.

Item	Case study	Within allowable range?	Reference
Water type	Potable water	Yes	Table 4-1 of this report
Flow rate in flow tube with highest flow rate	To be determined in this case study for specification with total flow of ≤ 130 L/s required.	Between 2 to 8 L/s	Table 4-1 of this report
UVT	≥ 90%	Yes, for potable water	Table 4-1 of this report
Redundancy required	Intermittent. Large clear water storage means shut down for up to three days is acceptable. Can operate outside the validated range for ≤ 5% of the water supplied in any one month (UVDGM page 6-13).	Yes	Table 4-1 of this report
Flow tube diameter	89 mm	Yes	Table 4-1 of this report
Reactor arrangement	As per the validated reactor	Yes	Section 3 of this report
Lamp arrangement	As per the validated reactor; no lamp to be over 8,000 hours old	Yes	Table 4-1 of this report
Information required	Design capable of 2.5 *Cryptosporidium* UVDGM log credit.	Yes	Section 6.2 of this report
Guideline required	UVDGM	Yes	Section 6.2 of this report

Table 8-4. Results of case study design.

Number of stages	UVT	Validated RED (UVDGM) mJ/cm²	Maximum flow rate per tube for the fastest tube (L/s)	Validation factor for *Cryptosporidium*	Validated *Cryptosporidium* RED (UVDGM) mJ/cm²	Validated *Cryptosporidium* log credit (UVDGM)
1	90%	35.2	3.5	4.14	8.5	≥ 2.5
2	90%	41.7	8.0	4.03	10.3	≥ 2.5

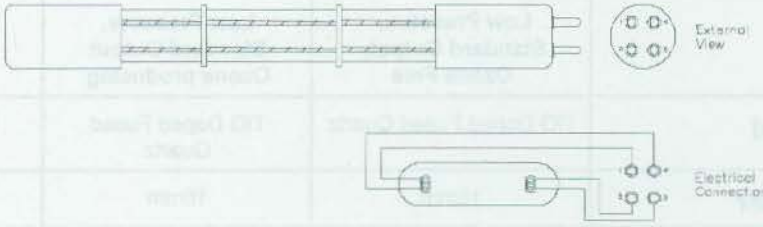
In summary, the chosen design to give a 2.5 log *Cryptosporidium* inactivation for potable water of UVT ≥90% treating a flow rate of ≤ 130 L/s includes two stages in series with 20 parallel 89 mm ø flow tubes per stage. In this case, additional stages are not required for supply continuity since under the UVDGM performance within the validated range needs only be achieved for 95% of any monthly period and there is sufficient clear water storage capacity to allow for some days of no supply to make any repairs or lamp changes.

9. Appendices

Following are appended design information, calibration certificates and layout diagrams to help illustrate the body of the report.

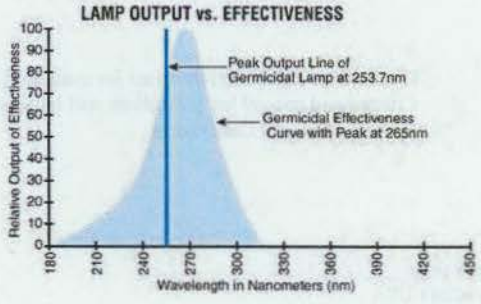
Lamp Specification

XUV64
001.0619055 UVL



A- Arc Length	1473 mm Nom
B- Base face to base face length	1558 mm (+/- 3mm)
C- Base face to opposite pin length	1565 mm Nom
D- Overall length pin to pin	N/A
Lamp Operating Current	800 mA
Lamp Operating Voltage	220 V
Lamp Starting Voltage @ 60 Hz	(preheat starter)
Lamp Wattage	155 W
UV Output 253.7nm (100 Hours)*	53 W calculated
Rated Average Life (85% of initial output)	10000 Hrs.
Wire type and insulation	7str. Cu/Ni-FEP
Wire Length	N/A
End termination	CERAL® 4 pin
Dimensions are nominal except as noted	
* 185nm radiation may reduce this value	

We hereby certify that data and values for the lamp noted above are true and represent the nominal operating values for said lamp when operated on the correct and proper ballast. The primary wavelength emitted from this lamp is 254nm.



2446 Cades Way
Vista, CA 92081 USA
T: 760.599.2644
F: 760.599.2642
info@enaqua.com

UVL STANDARD LAMP SPECIFICATIONS

	Low Pressure, Standard Output, Ozone Free	Low Pressure, Standard Output Ozone producing	Low Pressure High Output Ozone Free
Body Material	TiO Doped Fused Quartz	TiO Doped Fused Quartz	Pure Fused Quartz
Body Diameter	15mm	15mm	15mm
Mercury (mg)	>100mg	>100mg	>40mg Pellet
Mount	Molybdenum	Molybdenum	Molybdenum/Mica
Filament	Tungsten	Tungsten	Tungsten
Fill Gas	Argon	Argon	ArNe, ArNeXe
End Cap/Base	Ceramic or Ceral™	Ceramic or Ceral™	Ceramic or Ceral™
Solder	Pb Free	Pb Free	Pb Free
MSDS	On file	On file	On file
Arc Length tolerance	+/- 5mm	+/- 5mm	+/- 5mm
BF/BF Tolerance	+/- 3mm	+/- 3mm	+/- 3mm

Dimensions and materials noted for standard UVL parts.
Custom and special lamp products will have separate
Specification and Data sheets

2446 Cades Way
Vista, CA 92081 USA
T: 760.599.2644
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info@enaqua.com

CREATED: 01/03/07
REVISED: 09/30/07

UVC DETECTOR DATA SHEET
PART NUMBER:

Product	Detector Assembly	Detector Device
Manufacturer	Clear Water Technology	CLREX
Model Number	CL 705L	NSL5510
Package	T-05	T-05
Spectral Sensitivity		
Sensor Material		CdS
Peak sensitivity	260 nm +/- 10nm @ 12%T	5500 Å
Temperature Range	-50° to +75°C	-50° to +75°C
Acceptance angle	+/- 45°	+/- 45°
Linearity	Per Attached	Per Attached
Thermal Stability	Per Attached	Per Attached
Long Term Stability	Per Attached	Per Attached

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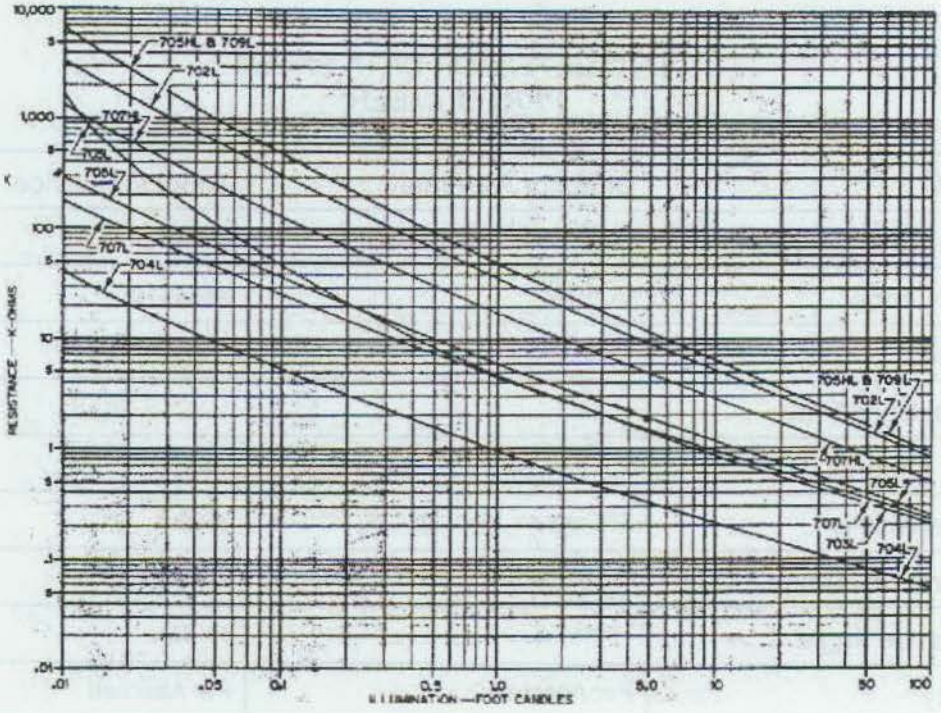
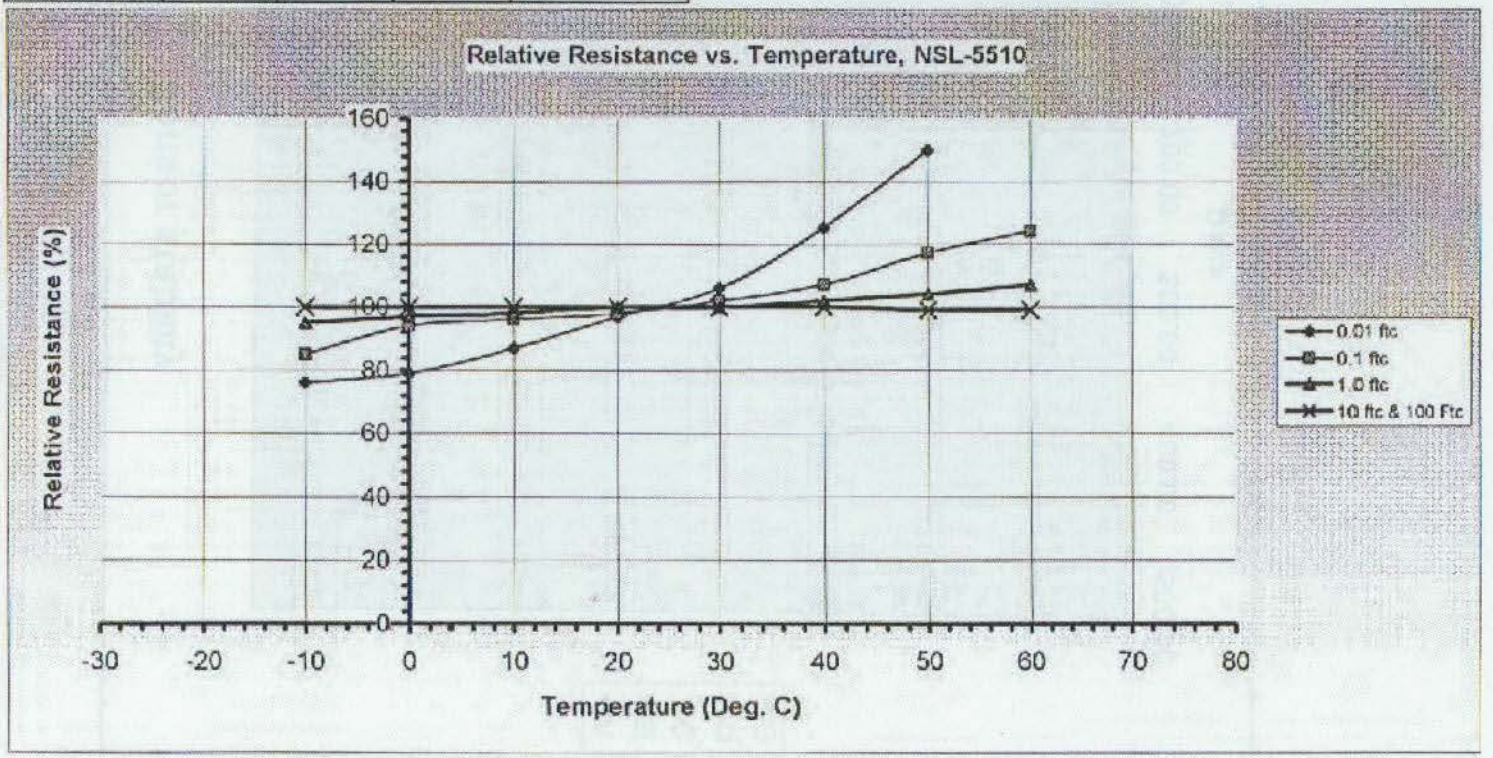
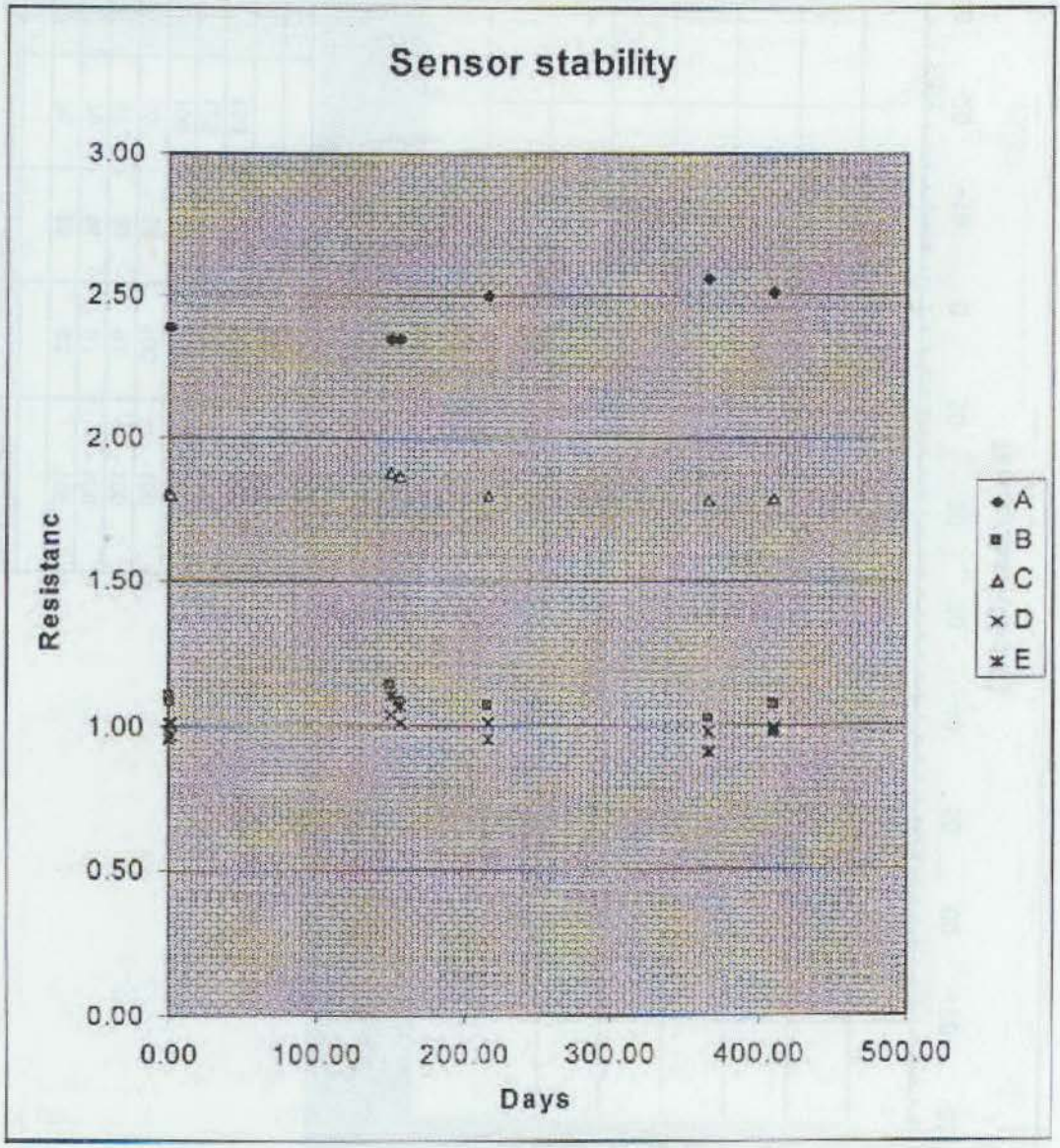
Cell Resistance Curves
Variation with Illumination CL-700 Series



Temperature	0.01 ftc	0.1 ftc	1.0 ftc	10 ftc & 100 Ftc
-20				
-10	76	85	95	100
0	79	94	97	100
10	87	96	98	100
20	97	98	100	100
30	106	102	100	100
40	125	107	102	100
50	150	117	104	99
60		124	107	99
70				





CERTIFICATE OF CALIBRATION

QSTA 0061 Issue 3

World Flow Technology Centres

ABB Limited
Oldends Lane, Stonehouse
Gloucestershire, GL10 3TA, ENGLAND
Tel: +44 (0) 1453 826661
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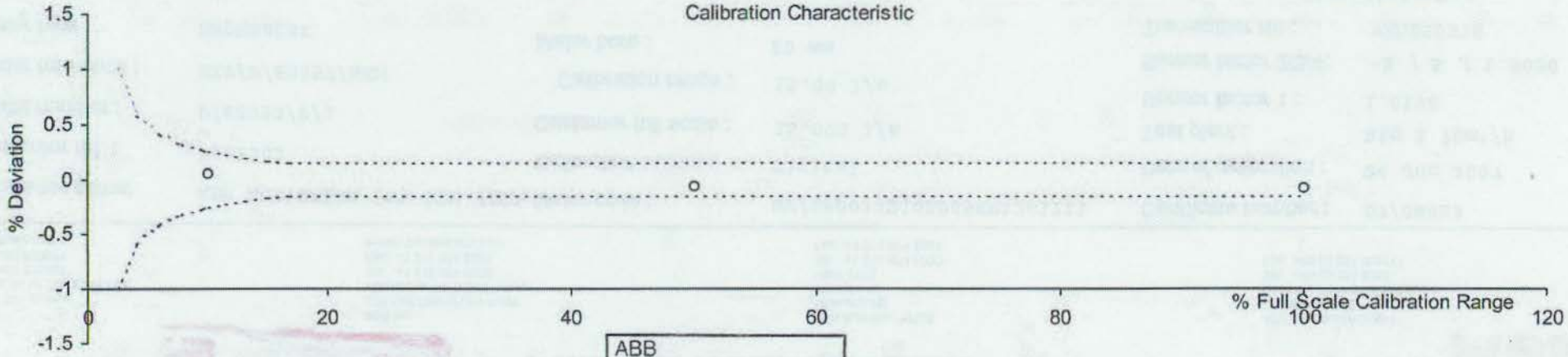
ABB Automation GmbH
Dransfelder Str.2
D-37079 Göttingen GERMANY
Tel: +49 (0) 551 9050
Fax: +49 (0) 551 905711

Customer name:	ABB AUSTRALIA PTY LTD (AUA	**Meter code :**	MF/E80037210A005ER1301111	**Certificate number :**	07/05656
Customer ref. :	5245232	**Calibration output :**	Digital	**Date of calibration :**	01 Jun 2007
Serial number :	P/67440/8/3	**Customer full scale :**	15.000 l/s	**Test plant :**	Rig 4 70m³/h
Order reference :	EXP/P/67440/NKM	**Calibration range :**	15.00 l/s	**Sensor factor 1 :**	0.9793
Meter type :	MagMaster	**Meter bore :**	80 mm	**Sensor factor 2/3/4:**	-10 / 5 / 1.0000
Tag Number :				**Transmitter No :**	vkh049028

				Reference						Meter Under Test		
Test Run number	Run Time sec	Water Temp °C Int	Ext	Stream 1 l/s	Stream 2 l/s	Stream 3 l/s	Stream 4 l/s	Stream 5 l/s	Total Flow l/s	Flowrate l/s	% Cal. range	% Error
1	100	21.6	0	15.017	0	0	0	0	15.017	15.005	100	-0.08
2	300	21.6	-	0	1.5021	0	0	0	1.5021	1.5029	10	0.05
3	100	21.6	-	7.5023	0	0	0	0	7.5023	7.4975	50	-0.06



Calibrator PHW

Approved by ABB 1098 ABB

Witnessed by

CERTIFICATE OF CALIBRATION

QSTA 0061 Issue 3

World Flow Technology Centres

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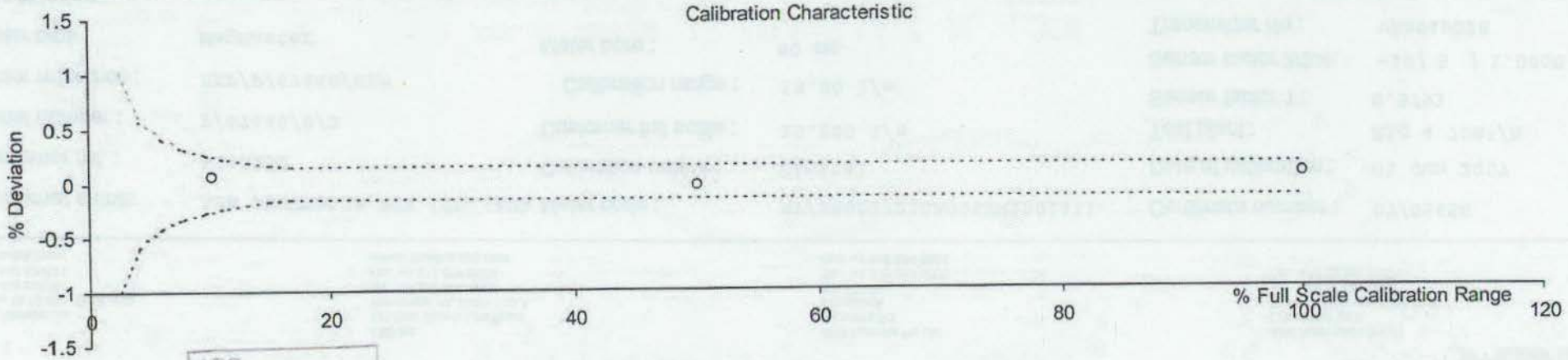
ABB Automation GmbH
Dransfelder Str.2
D-37079 Göttingen GERMANY
Tel: +49 (0) 551 9050
Fax: +49 (0) 551 905711

Customer name:	ABB AUSTRALIA PTY LTD (AUA	**Meter code :**	MF/E80037210A005ER1301111	**Certificate number :**	07/06823
Customer ref. :	5248302	**Calibration output :**	Digital	**Date of calibration :**	24 Jun 2007
Serial number :	P/68052/8/1	**Customer full scale :**	15.000 l/s	**Test plant :**	Rig 3 70m³/h
Order reference :	EXP/P/68052/NKM	**Calibration range :**	15.00 l/s	**Sensor factor 1 :**	1.0196
Meter type :	MagMaster	**Meter bore :**	80 mm	**Sensor factor 2/3/4:**	-5 / 5 / 1.0000
Tag Number :				**Transmitter No :**	vkh055575

		Reference						Meter Under Test		
Test Run number	Run Time sec	Water Temp °C Int	Water Temp °C Ext	Stream 1 l/s	Stream 2 l/s	Stream 3 l/s	Stream 4 l/s	Stream 5 l/s	Total Flow l/s	Flowrate l/s	% Cal. range	% Error
1	101	21.4	-	15.002	0	0	0	0	15.002	15.008	100.1	0.04
2	300	21.5	-	1.5302	0	0	0	0	1.5302	1.5312	10.2	0.07
3	101	21.5	-	7.5001	0	0	0	0	7.5001	7.497	50	-0.04



Calibrator ABB RKJ 1060 ABB

Approved by ABB 1070 ABB

Witnessed by

ORICA WATERCARE

USEPA 2006 Validated UV System Design Overview

Ravid Levy – Nirosoft Aust

Orica Watercare

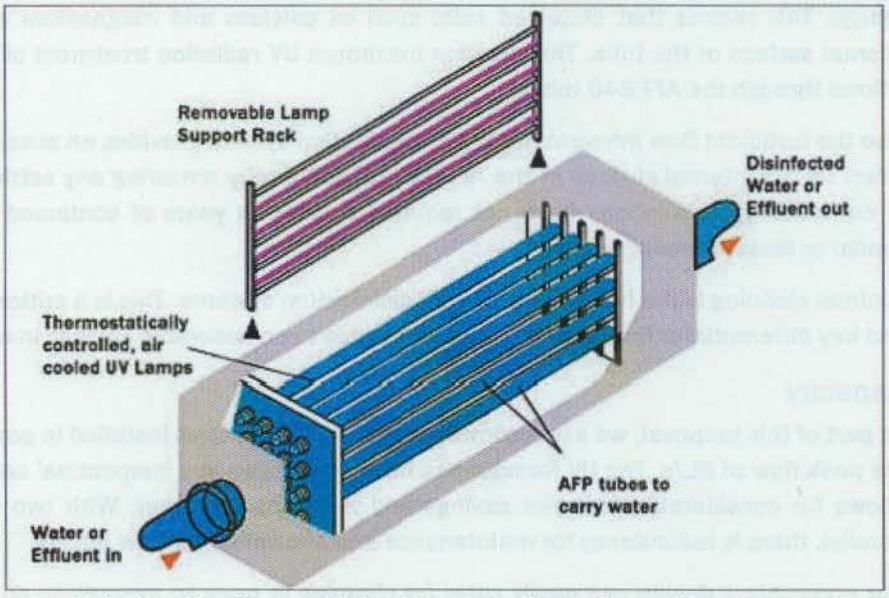
11 December 2008

Contents

Functionality

Design Overview

Our UV disinfection system is unique in that we offer a non-contact design where the effluent flows through Advanced Fluoropolymer tubes (AFP840) and the UV lamps and sensors are external to the effluent flow. The AFP840 tubes are robust, non-fouling and non-corroding. As the UV lamps are outside of the AFP840 tubes and not protected by quartz sleeves, lamp cleaning is not required. We submit that our system offers significant operating advantages in terms of faster lamp replacements and minimal cleaning requirements. This has a dramatic impact on plant uptime. We are confident that our non-fouling system will achieve the microbiological kill rates on a consistent basis with greater assurance. The graphic below conveys arrangement of UV lamps and AFP840 tubes in a typical UV Reactor.



Please contact Bob Arnold or Sunny Mishra for any further information.

Bob Arnold	0412 817 733	bob.arnold@orica.com
Sunny Mishra	0434 539 039	sunny@uvta.com.au
Orica Watercare (Glynde Office)	(08) 8337 0079	

Third Party Accreditation

Orica Watercare has undertaken a rigorous and refereed process to validate our UV disinfection systems in accordance with the USEPA *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface water Treatment Rule - 2006* (UVDGM Method) and the NWRI & AWWA *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse - Second Edition 2003.*

Dr Dan Deere of Water Futures Pty Ltd undertook the independent oversight of our validation work and can confirm that the UV disinfection system design we have submitted will deliver the UVDGM validated dose of 40mJ/cm^2.

Dr Paul Monis and his team of the Australian Water Quality Centre (AWQC) undertook the biodosimetry and collimated beam testing as part of the validation process in Adelaide.

UV System Performance

If the effluent quality can be guaranteed as a minimum of 80% UVT and the level of suspended solids is a maximum of 5ppm and turbidity is no greater than 2NTU, we can guarantee the required 0.5 log reduction in Adeno and 4 log reduction in Cryptosporidium.

This UV Reactor design is oversized to meet the stringent requirement of meeting the above design guidelines and the close to 4-log reduction in microorganisms. If the UVT is higher as would be expected from the upstream MBR process and UF system, higher flows through the UV system would be possible.

Cleaning Process

One of the key advantages of the non-contact UV disinfection system is the absence of regular, required cleaning. The AFP840 tubes that carry the effluent have a very low surface charge. This means that dissolved salts such as calcium and magnesium do not foul the internal surface of the tube. This ensures maximum UV radiation treatment of the effluent as it flows through the AFP840 tubes.

Also the turbulent flow inherent in our UV disinfection system provides an automatic cleansing effect on the internal surface of the AFP840 tubes thereby removing any settled solids. Many of our existing installations have not required a clean in years of continued operation with similar or lesser effluent quality.

Minimal cleaning is the hallmark of our UV disinfection systems. This is a critical advantage and key differentiator for our design and translates to considerable savings in running costs.

Capacity

As part of this proposal, we are recommending two UV Reactors installed in parallel to achieve the peak flow of 8L/s. The UV Reactor has been configured in a 'serpentine' configuration that allows for considerable footprint savings and a compact system. With two UV Reactors in parallel, there is redundancy for maintenance and allowance for flow pacing.

Our non-contact design can easily cater for changes in peak to average to no flow situations without any adverse effects on the UV lamps. This is a significant advantage over traditional quartz sleeve systems.

UV Reactor Operation

In normal operation, the UV Reactors will be active. Based on the flow signalling from the plant SCADA, the UV Reactor # 1 will have all the lamps in operation to achieve the necessary log reduction in microorganisms. As flow exceeds 4L/s, UV Reactor # 2 will be operational. This flow pacing mechanism will lead to considerable power savings, as only the required lamps will be in operation.

It should be noted that we do not anticipate frequent UV lamp or ballast failures. A complete UV Reactor failure will be an extremely unlikely scenario. Note that with two parallel flows, a complete plant shutdown is not necessary for lamp changes or any maintenance.

The level of suspended solids (more than 20ppm), turbidity (greater than 2NTU) and metal particles (iron greater than 0.5ppm) will impact effluent UVT and thereby UVI. It is critical that such factors are controlled and within the design limitations.

SCADA and Control Requirements

The UV system will have a common control cabinet from Rittal (400mm x 400mm). A common touch-screen HMI will be provided for all operational needs. The system can be interconnected to existing plant controls over ethernet. Furthermore, it can be remotely monitored over the Internet.

Display data provided at a glance on the HMI:

- ☐ Operational status of individual reactors and error signals
- ☐ Individual lamp and component status
- ☐ Advanced signal for lamp service or replacement
- ☐ UVT measurements
- ☐ Ambient reactor temperature and individual components
- ☐ Individual lamp and system run hours
- ☐ System flow rate

Instrumentation provided by us:

- ☐ UVI monitor
- ☐ Temperature sensors to measure reactor health
- ☐ Relays to activate heat exchangers

Based on an analog signal from a flow meter, our system will undertake flow pacing. This means that only the required lamp racks will be operational.

Quality Workmanship & Low Maintenance

Systems

The proposed systems will have base frames manufactured from "hot dipped" galvanised steel, body fabrication, internal component work done in our Glynde site in Adelaide, Australia. The finishing work, wiring, quality assessment, design specification checks and final testing will also be undertaken at our Glynde site in Adelaide before delivery to site. Orica Watercare (UVTA) operates with the Six Sigma principles for quality management to ensure that the final UV disinfection system meets all required specifications in a timely manner.

Orica Watercare (UVTA) has a strict Safety, Health and Environment policy and will undertake any work on site under a clearance to work process. All potential risks will be identified and an action plan to manage the risks will be implemented before work starts. A training package specific to the system will be developed and delivered by our commissioning personnel.

Cleaning System

As our UV disinfection is a non-contact design and does not use quartz sleeves, there is no need for automated wiper systems. As mentioned before, our only potential cleaning need would be a high-pressure water wash to clean the internal walls of the AFP840 tubes.

Replacing UV Lamps

Since each of our lamp stages is self-contained and modular, a lamp replacement in one stage can be carried out quickly. Similarly, our lamp racks are self-contained and in case of failure can be changed quickly. This modular aspect of our UV disinfection systems leads to quick and painless maintenance.

Since the UV Reactor proposed offers flexibility with two parallel flows, a complete plant shutdown is highly unlikely. The expected downtime from UV system issues is insignificant.

Lamp Life

The UV lamps used in our reactors are rated for greater than 80% output at 10,000hrs. As the lamp approaches its end of life, the Touchscreen on the Control Cabinet provides an advanced warning. This serves as a reminder to order and prepare for lamp replacements. We have existing arrangements with a recycling company (ISO4001 accredited) in Melbourne, Australia who dispose the used lamps in an environmentally responsible manner. The cost for this disposal service is included as part of our proposal as long as the replacement UV lamps are ordered from us. The lamp replacement process is described above.

Further steps will be outlined in the Instruction Manual and will be adequately explained in the training program for the plant operators.

USEPA 2006 VALIDATED
UV DISINFECTION SYSTEM
0.5 LOG IN ADENO / 4 LOG IN CRYPTO

CRITERIA	FIGURES	NOTES
Make	Orica Watercare	Fabrication, assembly and QA in Adelaide
System	Two UV Reactors In Pipe	UV Reactors installed in parallel
UVT%	80	Critical design setpoint but expected to be higher
Peak Flow Rate (L/s)	4 (Two required)	Two such reactors will service the full flow of 8L/s
Validated UV Dose	>40mJ/cm^2	0.5 Log in Adeno, 4 Log in Crypto as per USEPA
# Reactors	2	For the entire flow stream of 8L/s
# Lamp Stages / Reactor	6	UV Reactor has 6 self-contained lamp stages
# AFP Tubes / Reactor	6	60mm in diameter, non-corroding, non-fouling AFP tubes will carry the process flow in a serpentine arrangement in a column
# Lamps / Reactor	16	Lamps arranged on sides of the AFP tube column
# Ballasts / Reactor	8	Ballasts enclosed in the UV Reactor
Headloss (mm)	<1000	At maximum flow
Max Pressure (kPa)	450	Critical design setpoint
HMI Touchscreen	1	UL508A rated cabinet for controls / circuitry / HMI, common to both units (600mm x 600mm)
Cooling System	1	Thermostatically controlled UV Reactors with fans
Controls / Instrumentation	1	System can be connected to the plant SCADA over ethernet using MODBUS. Display data includes status messages, error conditions, lamp and system run hours, flow rate, UVT measurements.
UV Enclosure	1 (Footprint 2.5m x 2.5m)	Any enclosed space such as a shed would suffice
Total Power Draw (kW)	5 (Both UV Reactors)	Includes UV Lamps, fans, system controls
Power Supply	240V	At most 10 amps will be drawn at system start-up
Redundancy (%)	50 (at peak flow)	Allows for turn-down for maintenance or lower flows
Conceptual Drawings	**Drawing NIRO-001**	**Refer for further details and clarification**

UV LAMP		ELECTRONIC BALLAST		SUPPLIED INSTRUMENTATION	
Rated Hours	10000	Voltage (± 10% V)	100 - 270	UVI Sensors / Reactor	1
UV Output (watts)	55	Operating Freq (Hz)	50 - 150	Cooling System / Reactor	1
Power Usage (watts)	155	Power Efficiency (%)	95	Control Panel / System	1
Arc Length (mm)	1400	Temp Protection (C)	75	HMI Touchscreen / System	1

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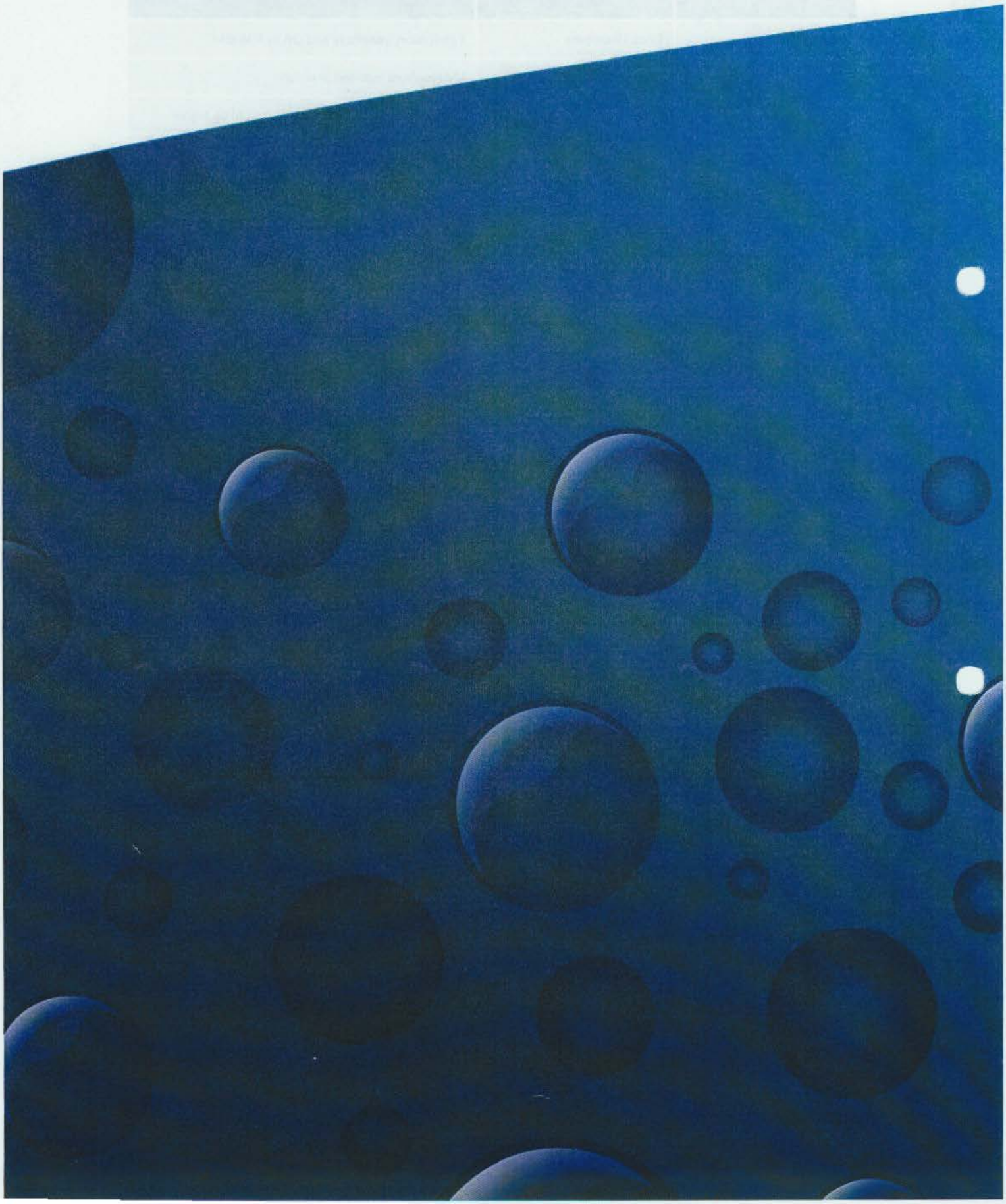
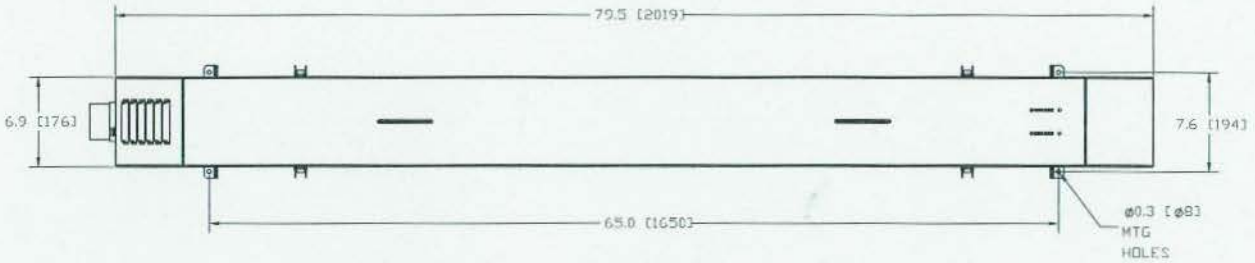
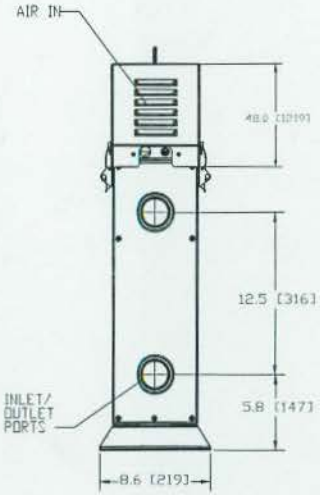
WATERCARE



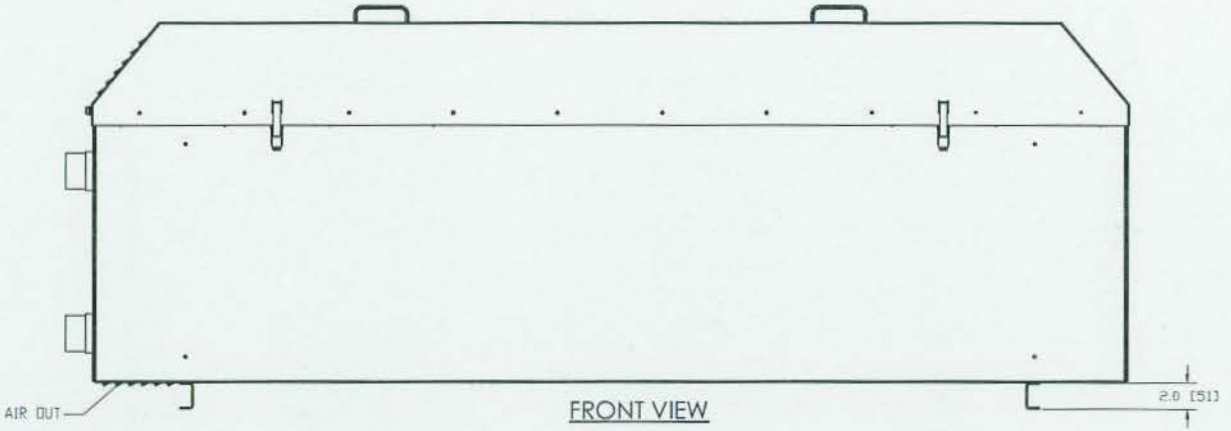
The two UV Reactors can be installed really close (100mm), but allowance should be made on either sides for access (300mm)

TOP VIEW





INLET / OUTLET CONFIGURATION



FRONT VIEW

END VIEW

Two such units will be installed in parallel for the max flow of 8L/s for a Validated UV dose of 40mJ/cm2 as per USEPA 2006 Guidelines

DO NOT SCALE DRAWING. This drawing is the property of ORICA and is not to be reproduced or modified without express permisssion. ALL MEASUREMENTS IN MM	71 Lewis Road, Glynde, South Australia - 5070 ORICA WATERCARE Ph: +61 8 8337 0079 Fax: +61 8 8337 9465 Email: uvta@uvta.com.au	TITLE: 4L/s UV REACTOR 40mJ/cm2 VALIDATED DOSE	CLIENT: RAVID LEVY NIROSOFT AUST
		MATERIAL: N/A	DWG NO.: NIRO - 001 REV: A
		DATE: 11/12/2008 WEIGHT: N/A	SCALE: 1:10 SHEET: 1 OF 1 A3

Solo Water

Appendix 4.2.15 **Reject Pond Water Balance Report**

Reverse Osmosis Reject Evaporation Pond Water Balance

for the

Catherine Hill Bay Water Utility, at Catherine Hill Bay Residential Subdivision

July 2013

Prepared for: Wayne Williamson
Solo Water Pty Ltd

Project Number: H10052
Project Name: Catherine Hill Bay
Report Number: H10052_R4B

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DOCUMENT CONTROL

Report Number: H10052_R4

ISSUE	STATUS	DATE	ISSUE DETAILS	AUTHOR	APPROVED
A	DRAFT	14/04/2013	FOR IPART LICENSE APPLICATION	ES	BRADLEY IRWIN MIEAust, CPEng, NPER
B	DRAFT	10/07/2013	FOR REVISED IPART LICENSE APPLICATION	ES	BRADLEY IRWIN MIEAust, CPEng, NPER

COMMERCIAL IN CONFIDENCE

DISCLAIMER

This report has been written for exclusive use by Solo Water Pty Ltd for the Solo Water Catherine Hill Bay Water Utility based on the agreement with Harvest Water Management Consultants Pty Ltd.

The investigation was carried out based on the specific requirements of Solo Water Pty Ltd and may not be applicable outside of this specific scope. Therefore the information in this report shall not be relied upon by any third party without further input from Harvest Water Management Consultants Pty Ltd.

The investigation has been undertaken based on information provided by others. Harvest Water Management Consultants Pty Ltd accepts no responsibility for the accuracy of information provided by others. The accuracy of the investigation and report is dependent on the accuracy of this information.

Reverse Osmosis Reject Evaporation Pond Water Balance

for the

Catherine Hill Bay Water Utility, at Catherine Hill Bay Residential Subdivision

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1 Introduction

Solo Water has entered into an agreement with the Rose Property Group to provide an integrated water, sewerage, recycled water and retail service provider solution for the approved residential subdivision at Catherine Hill Bay. The provision of private water services is permitted under the Water Industry Competition Act (New South Wales Government, 2006) and is administered by the NSW Independent Pricing and Regulatory Tribunal (IPART).

Once approved the scheme will be 100% owned, operated and maintained by the Catherine Hill Bay Water Utility (CHBWU) and funding of the scheme will be provided through rating of individual customers in the scheme as is the case with conventional water authorities. The CHBWU will take on all risks associated with the scheme and will operate the scheme in accordance with the license issued by IPART.

Harvest Water Management Consultants Pty Ltd was engaged by Solo Water to assist with the preparation of the IPART application and associated investigations. This Reverse Osmosis (RO) Reject Evaporation Pond Water Balance report has been prepared to demonstrate an effective method for managing RO Reject waste water from the Stage 2 Advanced Water Treatment Plant (AWTP) using a low energy method comprising of a Vetiver wetland and evaporation ponds. Details of the proposed strategy, modelling and results are outlined in this report.

1.1 Project Scope

The scope of this investigation is to:

- Develop a low energy onsite RO reject waste management strategy based on an evapotranspiration wetland and evaporation ponds;
- Undertake water balance modelling to demonstrate the proposed evaporation ponds are appropriately sized to avoid frequent overflow events;
- Demonstrate through water balance modelling that the proposed strategy will not result in significant environmental impacts or frequent overflow events.

2 Background

2.1 Site Location

The proposed scheme is located inside the approved footprint of the Catherine Hill Bay residential subdivision at Montefiore Street, Catherine Hill Bay in New South Wales. The site is located at the southern end of the Lake Macquarie City Council region. An overview of the approximate site location is provided below in Figure 2.1.

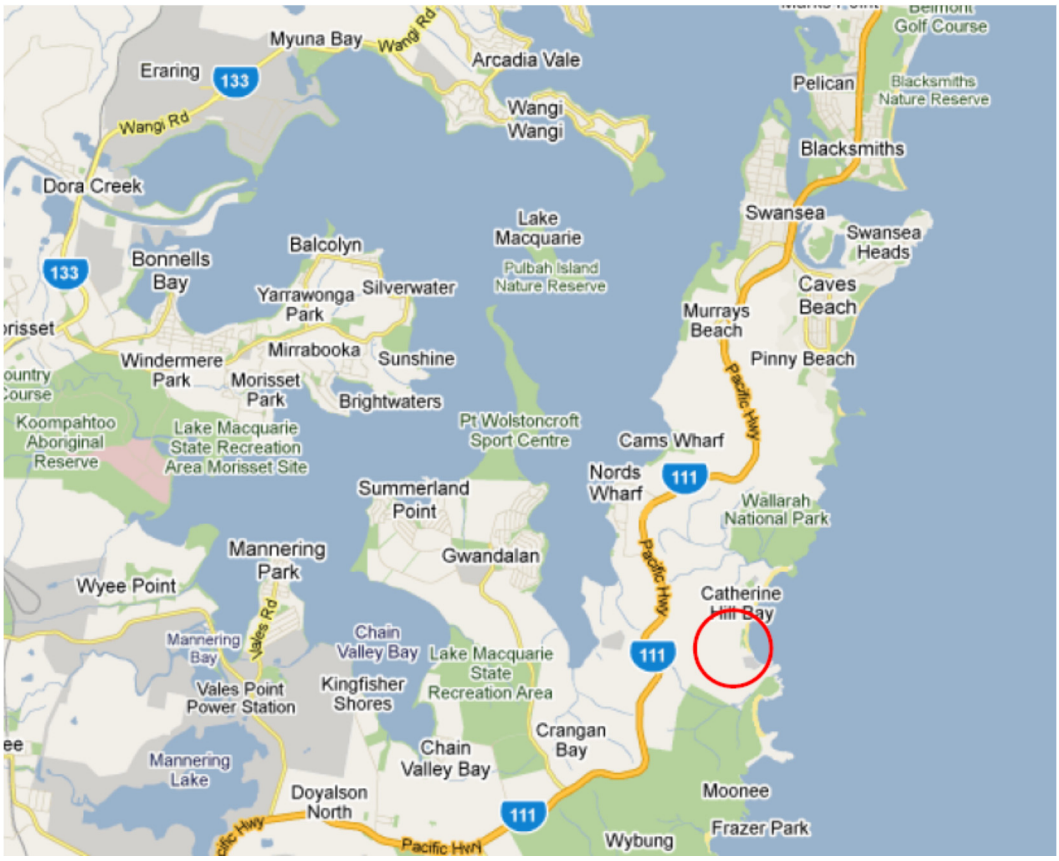

Figure 2.1: Site Location (source: Google Maps)

2.2 Waste Water Source and Characteristics

The CHBWU will supply potable and non-potable water to individual houses in the scheme under a dual reticulation arrangement. The source of non-potable water is domestic wastewater generated inside the CHBWU scheme.

All non-potable water supplied in the dual reticulation is treated in a Membrane Bioreactor followed by treatment in the Advanced Water Treatment Plant (AWTP). The AWTP uses Ultrafiltration membranes, ultraviolet disinfection, chlorine contact and salinity control using a side stream reverse osmosis (RO) process. The RO process for salinity control is required to ensure long term accumulation of salt in the recycled water supply system does not occur. For further information on the AWTP including process flow diagrams and layout plans refer to Appendix 4.2.1 and Appendix 4.2.3 in the IPART application.

The side stream RO process produces a concentrated waste stream that must be managed onsite in a sustainable manner. The production of waste concentrate is proportional to flow through the AWTP and feed water salinity.

The AWTP has a nominal design capacity of approximately 200 kL/day with approximately one-third of the flow treated in the side stream RO process. To minimise reject generation the RO process will be designed with a recovery rate of 85%. The system is therefore estimated to produce approximately 7.7 kL/day of RO reject with Total Dissolved Solids (TDS) concentration of approximately 4700 mg/L. This corresponds to a salt concentration of approximately one-seventh of sea water strength.

This waste stream will be managed onsite using a low energy system comprising of a vetiver grass evapotranspiration wetland and 2 x 2000 m^2 evaporation ponds. The strategy is discussed in the following sections of the report.

.

3 Overview of Proposed Reverse Osmosis (RO) Reject Management Strategy

A schematic overview of the proposed RO reject waste management system is provided below in Figure 3.1. RO reject wastewater will be managed with a number of measures that are outlined in the following sections including:

- RO Reject waste minimisation strategy;
- Evapotranspiration wetland planted with salt tolerant Monto Vetiver grass;
- Evaporation ponds;
- Final disposal of brine concentrate and salt residue to approved landfill facility.

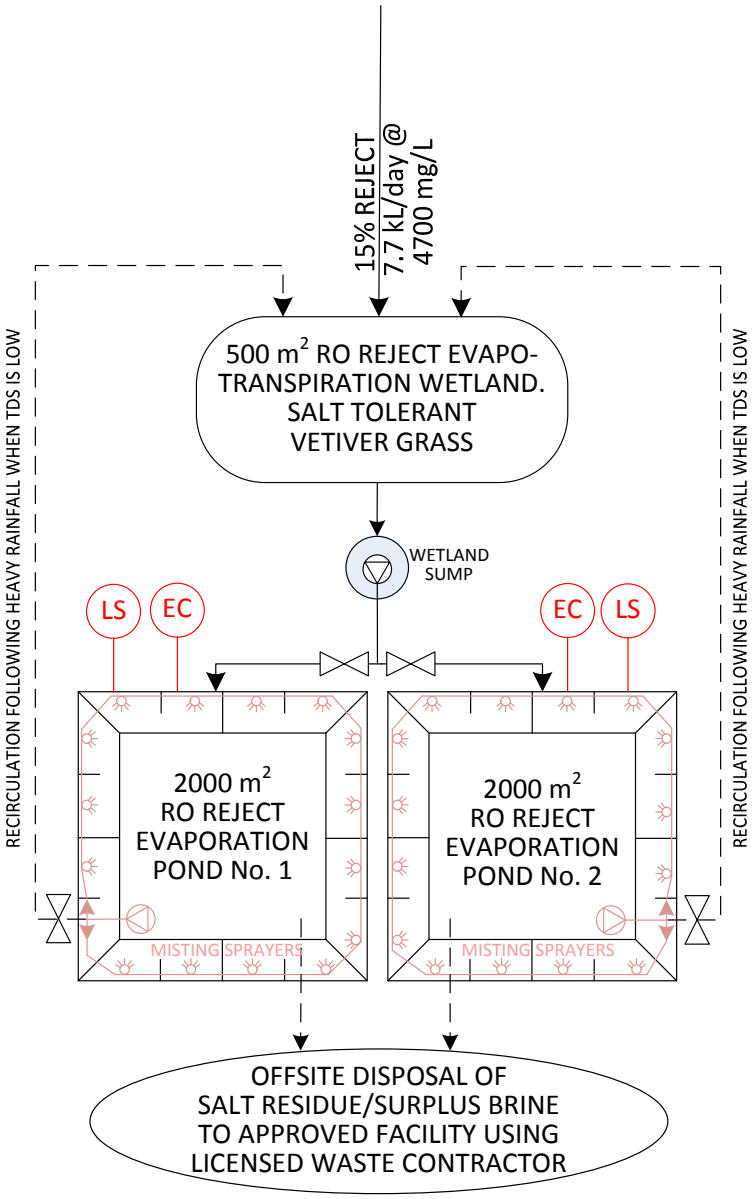

Figure 3.1: Reverse Osmosis Reject Management Process Flow Diagram

3.1 RO Reject Waste Minimisation Strategy

The volume of RO Reject waste water will be minimised through implementation of waste minimisation measures. Details of the waste minimisation strategy measures are included below in Table 3.1.

Table 3.1: RO Reject Waste Minimisation Strategy Measures

Measure	Description
Residential supply agreements	Mandatory new customer contracts and access agreements that outline the responsibilities of the resident with regard to appropriate water usage, waste and chemical management practices.
Trade waste agreements	Mandatory trade waste agreements for each commercial customer that outline the responsibilities of the commercial tenant with regard to appropriate water usage waste and chemical management practices.
Ongoing monitoring and awareness education	Ongoing monitoring of raw wastewater and effluent flows, salt concentrations and other contaminants. Ongoing awareness and communication with existing customers through additional information provided at each billing cycle.
Maximum recovery rate	A recovery rate of 85% from the reverse osmosis (RO) process has been designed into the system producing a waste stream of approximately 7.7 kL/day with TDS of 4,700 mg/L. This is the maximum recovery rate possible without excessive energy consumption and capital costs.

3.2 Monto Vetiver Grass Evapotranspiration Wetland

The RO reject waste stream will flow to a 500 m^2 subsurface flow Vetiver wetland where natural processes will reduce the volume of water and uptake some of the nutrients from the waste stream prior to being discharged to the evaporation ponds.

Monto Vetiver is a salt tolerant crop with high evapotranspiration and nutrient uptake rates. It is estimated on average the vetiver wetland will lose approximately 3 mm/day to evapotranspiration, thus reducing inflow to the evaporation ponds by approximately 1.5 kL/day with no reduction in salt load. The resulting outflow from the wetland to the evaporation ponds is estimated to be 6.2 kL/day with TDS of 5,800 mg/L.

The salinity threshold for Monto Vetiver grass is approximately 5300 mg/L TDS (Truong, Gordon, & Armstrong, 2002). At salt concentrations above this point reductions in yield occur. A 50% reduction in yield for Vetiver grass occurs at salt concentration of approximately 13,000 mg/L TDS. At the estimated outflow concentration from the vetiver wetland of 5,800 mg/L, plant yield is expected to reduce to approximately 95%. The wetland is therefore not expected to be significantly impacted by salinity provided that salt is evenly flushed through the wetland.

The Vetiver wetland will include the following:

- 500 m^2 salt tolerant Monto Vetiver grass;
- Subsurface flow to promote flushing and to avoid accumulation of salt;
- Coarse gravel (say 20-30 mm) at the inlet and outlet ends, and pea gravel (say 10 mm) used through the wetland matrix. The use of soils and clays should be avoided to minimise salt absorption/accumulation in the wetland;
- HDPE lined to minimise seepage to groundwater;
- Outlet sump with pump and level monitoring to control flows out of the wetland.

3.3 Evaporation Ponds

Water from the vetiver wetlands will be pumped in a controlled manner to two evaporation ponds that will be operated on an alternating fill and dry cycle. Each pond will have a total depth of 1.5 metres and a surface area of 2000 m^2.

The ponds will be filled one at a time to a maximum depth of 1.2 metres and then rested to allow stored water to evaporate. Filling to 1.2 meters provides a 0.3 metre freeboard to allow for heavy rainfall during the drying out period. Evaporation rates in the pond will be maximised through the use of a spray misting system and black HDPE liner. Once the pond is dried out accumulated salt residue and brine concentrate will be transported off site to the nearest accepting waste management facility by licensed Solo Waste Recovery vehicles. Details of the evaporation ponds are as follows:

- Total surface area of 4000 m^2 made up of 2 x 2000 m^2 ponds;
- Total pond depth of 1.5 metres with a fill depth of 1.2 metres and 0.3 metre freeboard;
- Black HDPE liner to avoid seepage to groundwater and to increase the solar absorption and water temperature in the pond;
- Low level sump at one end using a standard stormwater pit to allow emptying of the pond for clean out, salt/brine removal and maintenance;
- Spray misting system around the perimeter of the pond to increase evaporation rates.

3.4 Operational Management

Under normal operating conditions, the evaporation ponds have been designed so that only one pond receives flow until the level in the pond reaches 1.2 m (0.3 m of freeboard), then the flow is diverted to the second pond and the first pond is allowed to dry out via evaporation. Operational management strategies to avoid overflows occurring, to enable removal of concentrated brine and precipitated salt and for monitoring and continuous improvement are described in Table 3.2 below.

Table 3.2: Operational Management Strategies

	Description
Normal Pond Cycling	• Only one pond receives inflow at a time. • Each pond receives inflow until the maximum fill level of 1.2 meters is reached, following which the pond is rested to allow stored water to evaporate over the next 1-2 years. • The rested pond does not receive inflow until the water level has reduced sufficiently to allow the pond to be cleaned out with all salt and brine concentrate removed for offsite disposal.
Overflow Management	• If prolonged heavy rain causes pond level to fill within the 0.3 m freeboard and approach overflow level, a high level alarm will be raised to allow the operator appropriate time to undertake the necessary actions required to prevent overflow. Water balance modelling discussed in Section 4 shows this is predicted to occur less than once in 4 years on average. • If required Solo Waste Recovery trucks will be used to remove water from the full pond to ensure no over flow occurs. Water will be transported offsite to the nearest accepting licensed waste facility. • Trucks will be notified and appropriate time allowed to avoid any overflow occurring. • In operation decisions can be made to avoid overflows by other means, e.g. transfer of water between ponds, temporarily store water in the free board in the vetiver wetland, turn off the AWTP and use potable water in the non-potable water network.

	Description
Salt/Brine Management	• Concentrated brine and salt precipitate will be removed from the rested pond once it has sufficiently dried out; • Solo Waste Recovery trucks will be used to remove the final waste products from the ponds and transport it to the nearest accepting licensed waste facility; • Each pond will be cleaned out and the majority of salt residue removed before bringing the pond back online to receive inflow.

Monitoring	• Continuous online monitoring of water level in the Vetiver wetland and each evaporation pond with adjustable alarms will be set at the following pond levels:
	  ○ Pond empty < 0.1 metres
	  ○ pond fill level >1.2 metres
	  ○ Pond high Level >1.3 metres
	  ○ Pond overflow imminent >1.4 metres
	• Flow meters to measure daily flows into and out of the Vetiver Wetland and into and out of each evaporation pond to refine the site water balance;
	• Electrical conductivity monitoring of MBR effluent, RO reject water and in each pond;
	• Records of volumes/weight of brine/salt removed by road tanker for offsite disposal;
	• Rainfall monitoring onsite using an automatic weather station.

4 Water Balance Modelling

A daily time step water balance model using 100 years of rainfall data was setup in Microsoft Excel to simulate the water and salt balance in the two evaporation ponds. The performance of a number of different scenarios was investigated in the modelling exercise, however only details of the adopted option have been included below.

4.1 Modelling Inputs & Assumptions

A summary of the adopted input parameters and assumptions used in the modelling is presented below in Table 4.1.

Table 4.1: Model Input Parameters & Assumptions

Parameter	Value Adopted	Description
RO reject characteristics	7.7 kL/day @4200 mg/L TDS	AWTP nominal production capacity of approximately 200 kL/day with around one third of flow undergoing treatment in the RO system. RO system recovery rate of 85%.
Vetiver wetland evapotrans-piration	3 mm/day on average	3 mm/day adopted as an average daily evapotranspiration loss from the wetland, which equates to a 1500 L/day volume reduction for the 500 m^2 wetland. No reduction in salt load was assumed through the wetland hence wetland outflow was estimated to be approximately 6.2 kL/day @ 5800 mg/L TDS.
Pond Inflow characteristics	6.2 kL/day @5800 mg/L TDS 3.1 kL/day @5800 mg/L TDS (wet days)	Inflow to the ponds water assumed to be the outflow from the Vetiver wetlands with no losses. On days with more than 3 mm of rain, pond inflow was halved to account for the reduction in recycled water generation that would occur on these days due to reduced irrigation demand.
Pond Area	2 x 2000 m^2 ponds. Total area: 4000 m^2	Pond area is the maximum surface area when the pond is full at a depth of 1.5 metres. Water surface area was calculated each day based on the volume of water in the pond.
Pond Levels	Total depth: 1.5 m Fill depth: 1.2 m Freeboard: 0.3 m	Each pond is filled to a maximum depth of 1.2 meters before being rested to allow stored water to evaporate, thus leaving a 0.3 metre freeboard. Overflow occurs when pond level is above the maximum depth of 1.5 m.
Climate Data^	Daily rainfall data	100 years of daily Rainfall data * Station: Newcastle Nobbys Signal Station, BOM station # 61055 * Mean annual rainfall = 1123.5 mm * Modelling Period: 01/01/1913 to 31/12/2012 * Average monthly rainfall data can be found in Appendix A
	Average monthly evaporation data	Daily mean Class A Pan Evaporation data * Station: Williamtown RAAF, BOM station # 61078 * Mean annual evaporation = 1716.7 mm * Mean Monthly Evaporation data for period: 1974 to 2012 * Average monthly evaporation data can be found in Appendix A
	Rainfall – Evaporation deficit	Rainfall – Evaporation deficit = -593.2 mm/year which indicates that on average there is more evaporation than rainfall each year. Monthly rainfall-evaporation deficit data can be found in Appendix A

<table>
<tr><th>Parameter</th><th>Value Adopted</th><th>Description</th></tr>
<tr><td>Pond Factor</td><td>0.9</td><td>A pond evaporation factor of 0.9 was adopted to account for the reduction in evaporation that would occur from a shallow HDPE lined pond compared with a standard Class A evaporation pan.</td></tr>
<tr><td>Misting Factor</td><td>1.3</td><td>A misting factor of 1.3 was adopted to account for the increase in evaporation that would occur with the use of a spray misting system that effectively increases the water surface area for evaporation to occur.</td></tr>
<tr><td>Salinity Evaporation Factor</td><td>1.00 – 0.56</td><td>The salinity evaporation factors outlined below (Kokya & Kokya, 2006) were used to account for the reduction in evaporation that occurs with increasing salinity.
<table>
<tr><th>Salinity</th><th>0-0.2 g/L</th><th>40 g/L</th><th>80 g/L</th><th>160 g/L</th><th>350 g/L</th></tr>
<tr><td>Salinity Evapo Factor</td><td>1.00</td><td>0.94</td><td>0.81</td><td>0.69</td><td>0.56</td></tr>
</table>
Salinity in the model is calculated daily after inflow and rainfall to determine the appropriate Salinity Evaporation Factor for that day based on interpolation of the above data.</td></tr>
<tr><td>Total Evaporation</td><td>Calculated daily</td><td>Evaporation was calculated each day in the model after rainfall and inflow was added to the pond.
Pond Evaporation =
Pan Evaporation x Pond Factor x Misting Factor x Salinity Factor</td></tr>
<tr><td>Removal of brine/salt residue</td><td>20 kL</td><td>The modelling assumed that the pond was cleaned out and all brine and salt residue removed when the volume in the pond fell below 20 kL.</td></tr>
</table>

Daily water balance modelling was undertaken based on the data presented above in Table 4.1, modelling results are presented below in Section 4.2.

4.2 Modelling Results

A summary of the average water balance results over the 100-year modelling period for the 2 x 2000 m^2 evaporation ponds is outlined below in Table 4.2.

Table 4.2: Summary of average water balance results.

Measure		Units	Pond 1	Pond 2	Total
Pond Water Balance	RO Reject Inflow Volume	kL/Year	1,318.4	738.8	2,057.2
	Rain Volume	kL/Year	2,200.2	1,219.2	3,419.5
	Evaporation Volume	kL/Year	3,503.4	1,920.6	5,424.1
	Overflow Volume removed	kL/Year	0.3	34.1	34.4
	Concentrated Brine removed	kL/Year	3.4	3.3	6.7
	Change in Pond Volume	kL	11.5	0.0	11.5
Overflow Statistics	Volumetric overflow percentage	% of inflow	<0.03%	<4.61%	<1.67%
	No. of overflow events per 100 years	Events/100 yrs	2	23	25
	No. of overflow days per 100 years	Days/100yrs	3	216	219

Measure		Units	Pond 1	Pond 2	Total
	Average duration of overflow events	Days	1.5	9.4	8.8
	Maximum duration of overflow events	Days	2	62	62
	Average salinity of overflows	mg/L	11,724	8,748	8,778
Brine removal	No. of days where salt residue/brine concentrate removed from pond	Days/100yrs	18	18	36

As shown above in Table 4.1 the proposed evaporation ponds are predicted to overflow approximately 35 kL per year on average, which represents less than 1.7% of pond inflow. This could be managed with an average of 2 x 20 kL road tankers per year. Average salinity of overflow water was shown to be approximately 8,800 mg/L, or around ¼ of sea water strength.

In reality the overflow events do not occur every year but are concentrated to periods of heavy rainfall approximately every 20 years. During the 100-year modelling period there was 25 overflow events spread across 219 days, which equates to 1 overflow event every 4 years lasting for 9 days on average. The longest overflow event lasted for 62 days and occurred during the wet period in 1963.

The 25 overflow events are clustered into 5 distinct periods over the 100 year modelling period as shown below in Figure 4.1 that shows a plot of pond water level verses time. These overflow periods correspond to years with above average rainfall with the worst overflows occurring in 1950 and 1963 when annual rainfall was above the 95th percentile (see Appendix A for BOM rainfall data).

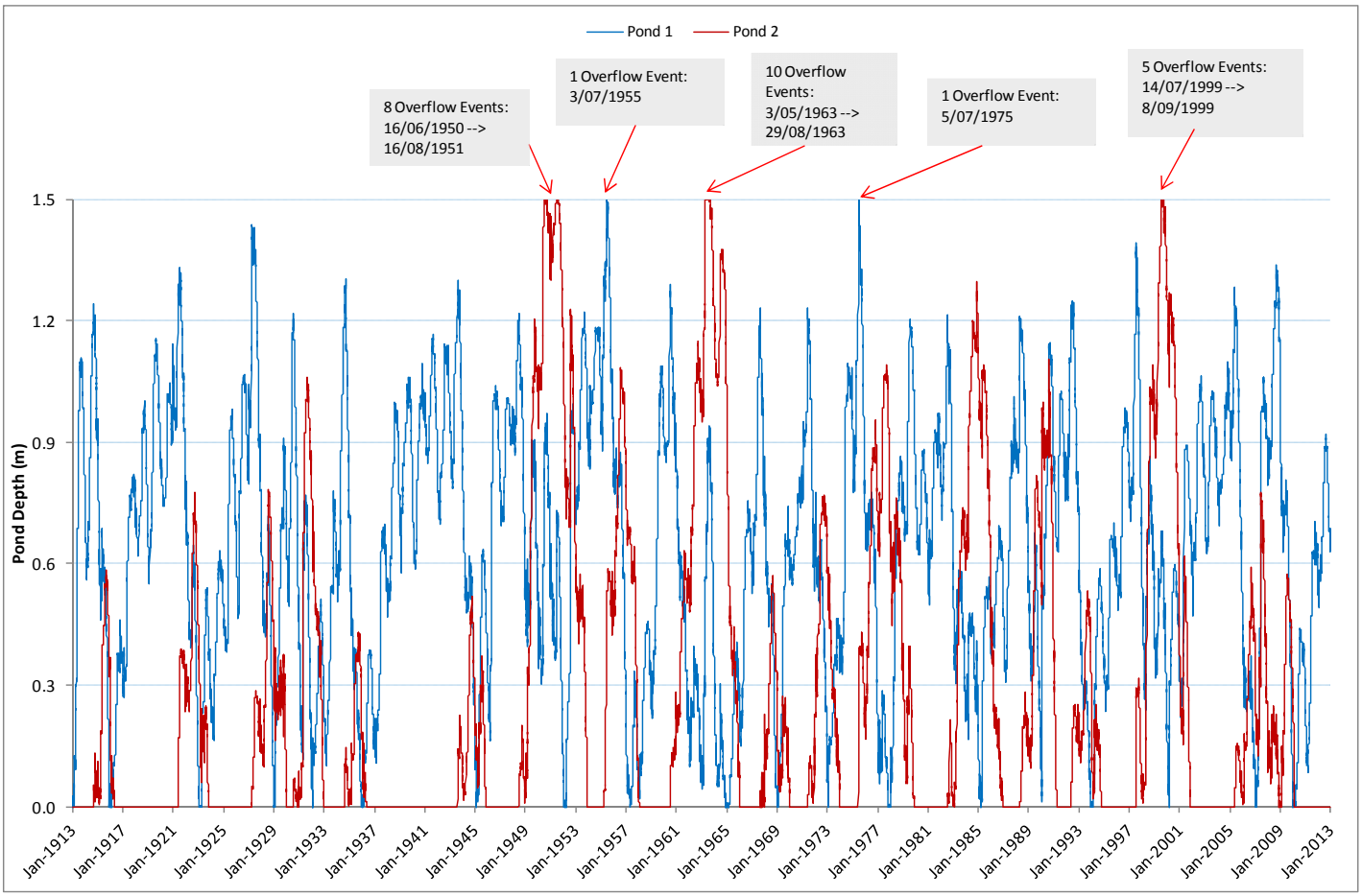

Figure 4.1: Pond Depth vs. time for the 100-year modelling period.

During the worst overflow event in June-July 1963 (one of the wettest years on record) the overflow event lasted for 62 days with total overflow volume of approximately 700 kL. In operation this would require approximately 35 x 20 kL trucks visits over the 62-day overflow event or around 1 truck visit every 1-2 days.

When a pond is being rested the modelling assumed all concentrated brine and salt residue would be removed when the volume of water in the pond falls below 20 kL. This occurred 18 times for each pond through the modelling period, which equates to about one 20 kL tanker every 2 to 3 years, or 6.7 kL/year as indicated in Table 4.2.

To illustrate the performance of the ponds and the amount of time at various critical pond depths, a Percentile chart of the pond levels with time is illustrated below in Figure 4.2.

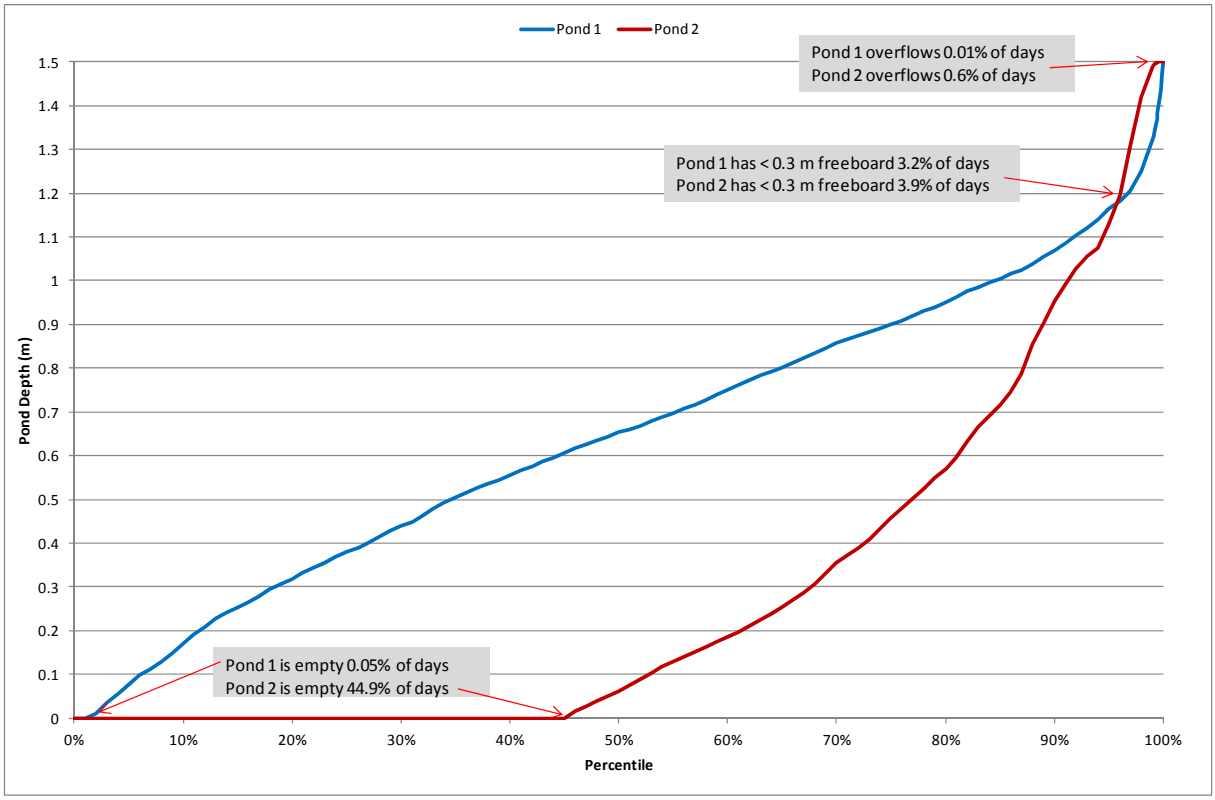

Figure 4.2: Pond Depth Percentile Chart

It can be seen in Figure 4.2, Pond 2 is empty almost half of the time because Pond 1 has been setup as the default receiving pond for modelling purposes and receives flow as soon as it has been emptied. Overflows occur for less than 1% of days in the modelling period and pond depth is greater than 1.2 m for less than 4% of days in the modelling period.

5 Conclusions

Harvest Water Management Consultants Pty Ltd was engaged by Solo Water to develop a strategy for the sustainable onsite management of RO Reject wastewater from the proposed Advanced Water Treatment Plant that will supply Class A+ recycled water to customers in the Catherine Hill Bay Water Utility scheme.

The proposed waste management strategy includes waste minimisation processes, a 500 m^2 evapotranspiration wetland planted with salt tolerant Monto Vetiver grass and 2 x 2000 m^2 evaporation ponds.

The evaporation ponds were sized to minimise the potential for overflow events so that any required offsite management during extreme wet weather would be infrequent and manageable using Solo Waste Recovery licensed waste vehicles.

Water balance modelling of the proposed RO reject management system has indicated that overflow events are expected to occur on average once every 4 years and last for 9 days. Water balance modelling indicates overflow events would account for less than 1.7% of the inflow volume to the ponds and would occur on less than 1% of days. These events are concentrated to periods of high rainfall every 10-20 years.

The proposed RO reject waste management system is therefore considered sustainable and unlikely to result in significant environmental impacts or risks to the local environment.

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Appendix A
BOM average monthly climate data.

Rainfall Data all years (1862-2013) - Station: Newcastle Nobbys Signal Station, BOM station # 61055													
Statistic	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Mean	88.4	107.9	119.6	116.0	117.3	117.1	94.6	73.6	72.5	72.9	70.5	81.1	1123.5
Lowest	2.0	0.5	2.8	0.0	2.1	0.8	0.0	0.0	0.8	4.6	2.4	4.6	596.9
5th %ile	15.9	11.5	23.9	17.0	15.5	17.1	11.4	6.1	9.9	10.7	9.1	15.7	765.1
10th %ile	24.4	19.6	29.9	26.3	23.5	22.1	15.9	12.6	16.5	17.1	14.8	21.0	794.2
Median	70.3	88.0	94.8	91.7	103.4	93.2	80.4	57.7	57.2	63.8	65.1	62.8	1048.4
90th %ile	174.6	213.9	242.4	235.4	228.9	245.6	198.3	139.5	146.4	141.1	135.0	155.1	1541.6
95th %ile	228.2	273.0	336.1	296.3	301.5	300.0	244.8	191.8	188.2	173.9	173.0	200.8	1625.6
Highest	404.0	559.2	544.4	546.4	441.3	495.8	351.1	545.3	283.1	277.5	203.9	326.5	1919.4
Evaporation Data for period: 1974 to 2012 - Station: Williamtown RAAF, BOM station # 61078													
Mean	213.9	175.2	151.9	114.0	83.7	75.0	80.6	111.6	141.0	170.5	189.0	223.2	1716.7
Monthly Rainfall – Evaporation Deficit													
Mean deficit	-125.5	-67.3	-32.3	2.0	33.6	42.1	14.0	-38.0	-68.5	-97.6	-118.5	-142.1	-593.2
90th %ile deficit	-39.3	38.8	90.5	121.4	145.2	170.6	117.7	27.9	5.4	-29.4	-54.0	-68.1	-175.1

Note: Daily rainfall data was used in the modelling exercise, monthly data is presented above for information only.