Validation of the Goreangab Reclamation Plant in Windhoek, Namibia against the 2008 Australian Guidelines for Water Recycling

Ian B. Law, Jurgen Menge and David Cunliffe

ABSTRACT

Australia has had Guidelines in place for water recycling (for all uses other than the augmentation of drinking water supplies) since 2006. These Guidelines were extended to cover potable reuse in May 2008 and have been applied to two potable reuse projects in Australia – one a trial plant in Perth, Western Australia and the second for a large AUD$2.6 × 10^9 scheme in Brisbane, Queensland. All reclamation plants in Australia must be 'validated' against the Australian Guidelines for Water Recycling prior to being put into operation. The majority of advanced reuse schemes incorporate the dual membrane process – microfiltration or ultrafiltration followed by reverse osmosis (RO) – in the treatment trains and while this membrane based treatment has been shown to produce a very high quality of product water, it does come at a cost and there is renewed interest in alternative treatment technologies that offer cost savings and are more sustainable. This paper uses data gathered in Australia from a range of advanced reclamation plants, as well as design and actual performance criteria from the Goreangab Plant, to 'validate' the latter and, given the longevity of the Windhoek direct potable reuse experience, lend support to more serious consideration of non-RO based plants for potable reuse applications.

Key words | process validation, sustainability, treatment technologies, validation guidelines

Ian B. Law (corresponding author)
IBL Solutions,
P O Box 226,
Wellington,
NSW 2082,
Australia
and
University of Queensland,
Brisbane,
Queensland 4072,
Australia
E-mail: *iblaw@bigpond.com*

Jurgen Menge
City of Windhoek,
P O Box 59,
Windhoek,
Namibia

David Cunliffe
Department of Health,
P O Box 6,
Rundle Mall,
South Australia 5000,
Australia

INTRODUCTION

Water recycling is playing a significant role in the diversification of Australia's water supplies and there has been significant growth in its application over recent years. Australia has had Guidelines in place for water recycling (for all uses other than the augmentation of drinking water supplies) since 2006. The Guidelines were extended to cover potable reuse in May 2008.

These Guidelines essentially focus on a risk management rather than a risk avoidance approach to ensuring the end product water quality, with a reliance on multiple barriers in the treatment train. The Guidelines focus on both acute and chronic health impacts and there is an acknowledgement that, with the multiple barriers in place, the critical issue is the acute health impact. All water recycling schemes in Australia have to be validated before operation to ensure that the overall log removal values (LRVs) required for virus, bacteria and protozoa for the particular end use in question are complied with – be it potable reuse, dual water supplies or unrestricted irrigation. These overall LRVs are the sum of the LRVs achieved across each of the individual process units and it is these individual LRV values that have to be validated before the plant can become operational.

The majority of advanced reclamation plants, particularly those that have been designed for potable reuse, in Australia incorporate the dual membrane system – microfiltration (MF) or ultrafiltration (UF) followed by reverse osmosis (RO). This process train appears to be the default process for many high end reuse schemes in Australia (as well as South Africa, California and parts of Europe) at the moment. However, experience is showing that this train, while producing an exceptional product water quality,

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is not as cost effective or as sustainable as those trains that incorporate ozone and activated carbon in lieu of RO – examples of which are the UOSA plant in Virginia, USA and the Goreangab Plant in Windhoek.

Given that Direct Potable Reuse has been practised in Windhoek, Namibia since 1968 and that the current Goreangab Plant does not have RO incorporated in its treatment train, this paper will validate the performance of this plant against the Australian Guidelines for Water Recycling (AGWR) and by so doing, lend support to more serious consideration of non-RO based treatment trains for potable reuse applications, not only in Australia but in other countries of the world.

AGWR – AUGMENTATION OF DRINKING WATER SUPPLIES

Australia has had Guidelines for augmenting drinking water supplies in place since May 2008 (Natural Resource Management Ministerial Council *et al*. 2008). These Guidelines are based on a risk identification and management principle and are linked into the Australian Drinking Water Guidelines (ADWG), that have recently been updated (ADWG 2011). They are intended to provide principles and a framework for the safe implementation of water recycling schemes and underwent both international and national review before being released.

Although these Guidelines are not mandatory and have no formal legal status, their adoption provides a shared national objective; at the same time, it allows flexibility of response to different circumstances at regional and local levels. Water recycling is regulated by States and Territories and these jurisdictions are free to use these Guidelines in conjunction with their own regulations to ensure that any local requirements are met.

The Guidelines discuss both indirect and direct augmentation and at the time of their production – May 2008 – there was a strong preference for the indirect alternative, much as was prevalent at that time in the USA and Europe. However, there is now increasing recognition that the direct augmentation option does have significant advantages.

The 'Key Principles' of the Guidelines are as follows:

- *Protection of public health remains paramount* – must be recognised and reinforced as the highest priority.
- *Community engagement and support is essential* – the consuming community are the ultimate arbiters of acceptability.
- *Institutional capacity must be in place* – management structures must be commensurate with the need to provide a safe drinking water, on a continuous basis.
- *Robust and reliable multiple barriers must be installed* – use of multiple barriers is the key to production of a safe drinking water and they must be maintained and monitored through the life of the schemes.
- *Personnel skills, training and accountability are essential* – personnel must have appropriate skills and training and be aware of the consequences of failure.
- *Effective trade waste (source control) programmes must be in place* – effective trade waste programmes must be in place to reduce the range and concentrations of chemicals discharged to the sewers.
- *Regulatory surveillance and auditing* – surveillance and auditing verify that schemes are managed and operated at levels that protect human health.

Microbial health based targets

The greatest risk to human health is that presented by microbial hazards. The AGWR use Disability Adjusted Life Years (DALYs), performance targets and reference pathogens for the evaluation of microbial health risk. This is based on the approach described in the World Health Organization (WHO) Guidelines for Drinking Water Quality (WHO 2011). The 'tolerable' microbial risk adopted in these guidelines is 10^{-6} DALYs per person per year, which is approximately equivalent to an annual diarrhoeal risk of illness of 10^{-3} (i.e. 1 illness per 1,000 people).

A quantitative microbial risk assessment (QMRA) can be applied to microbial hazards. The approach outlined in the AGWR uses the following reference pathogens: *Cryptosporidium* for protozoa and helminths, a *rotavirus* and *adenovirus* combination for enteric viruses, and *Campylobacter* for bacteria. The default 95th percentile values for these organisms (per litre of sewage) are given as 2,000 *Cryptosporidium*, 8,000 *rotavirus*, and 7,000 *Campylobacter*.

Using these values, and an average daily consumption of 2 L/person/day, the log reductions required to achieve compliance with the 10^{-6} DALY/person/year tolerable risk level can be calculated using the formula:

$$\text{Log Reduction} = \text{Log}\,(\text{Concentration in Source Water} \times 2\,\text{L} \times 365\ \text{days} \div \text{DALY}d)$$

where DALYd (the dose equivalent to 10^{-6} DALY) is 1.6×10^{-2} for *Cryptosporidium* ('total', not 'viable'), 2.5×10^{-3} for enteric viruses, and 3.8×10^{-2} for *Campylobacter*.

Using this formula, the minimum log reductions required for potable reuse are as follows:

- 8 logs for *Cryptosporidium*.
- 9.5 logs for enteric viruses.
- 8.1 logs for *Campylobacter*.

A combination of treatment processes is then required to cumulatively achieve these levels of log removals. Table 1, taken from the Guidelines, is a summary of indicative log removals for a range of enteric pathogens and indicator organisms across treatment technologies often applied in advanced water reclamation plants. In order to receive actual log removal credits, individual processes must be validated for the log removal credits being claimed, and regulators will only credit treatment processes with the maximum LRVs that can be continuously and reliably monitored by operational parameters. These LRVs tend to be lower than the removals shown in Table 1, particularly for the membrane removal processes such as UF and RO.

Chemical health based targets

Chemical safety is defined in terms of compliance with guideline values. Where chemicals are listed in the Drinking Water Guidelines, the same values are applied to the recycled water that is being used to augment drinking water supplies. However, where chemicals measured in recycled water are not listed in the Drinking Water Guidelines, the health guideline values are determined using the approach outlined in the document.

The Guidelines note that the maximum concentrations of most chemicals (some 500) that have been detected in published studies of secondary effluents are generally below guideline values. There were some exceedances for

Table 1 | Log removals for enteric pathogens and indicator organisms

	Indicative log reductions[a]							
Treatment	***Escherichia coli***	**Enteric bacteria (e.g., *Campylobacter*)**	**Enteric viruses**	**Phage**	***Giardia***	***Cryptosporidium***	***Clostridium perfringens***	**Helminths**
Secondary Treatment	1.0–3.0	1.0–3.0	0.5–2.0	0.5–2.5	0.5–1.5	0.5–1.0	0.5–1.0	0–2.0
Dual Media Filtration[b]	0–1.0	0–1.0	0.5–3.0	1.0–4.0	1.0–3.0	1.5–2.5	0–1.0	2.0–3.0
MF	3.5– > 6.0	3.5– > 6.0	0.5– > 6.0	3– > 6.0	> 6.0	> 6.0	> 6.0	> 6.0
UF, NF, RO	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0
Reservoir Storage	1.0–5.0	1.0–5.0	1.0–4.0	1.0–4.0	3.0–4.0	1.0–3.5	N/A	1.5– > 3.0
Ozone	2.0–6.0	2.0–6.0	3.0–6.0	2.0–6.0	2.0–4.0	1.0–2.0	0–0.5	N/A
Low UV	2.0– > 4.0	2.0– > 4.0	1.0– > 3.0	3.0–6.0	> 3.0	> 3.0	N/A	N/A
High UV	>6.0	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0	N/A	N/A
AOP	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0	N/A	N/A
Chlorination	2.0–6.0	2.0–6.0	1.0–3.0	0–2.5	0.5–1.5	0–0.5	1.0–2.0	0–1.0

N/A = not available.

[a]Reductions depend on specific features of the process, including detention times, pore size, filter depths and disinfectant.

[b]Including coagulation.

Source: Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, National Health and Medical Research Council (NRMMC/EPHC/NHMRC 2008).

NF = Nanofiltration, AOP = Advanced Oxidation Process.

a limited number of pharmaceuticals (alprazolam and valium), and some estrogenic hormones (ethinyl estradiol, estrone and mestranol) but no exceedances for antibiotics.

In addition, there were some exceedances for some compounds, for example N-Nitrosodimethylamine and chloroform (disinfection by-products), Demeton S (pesticide), paraxanthine (caffeine metabolite), benzo(a)pyrene (polyaromatic hydrocarbon) diatrizoic acid (contrast medium), 1,3-trimethylenedinitrilotetraacetic acid (chelating agent) and 5 methyl-1H benzotriazole (anti-corrosive agent). However, advanced treatment should reduce concentrations of these compounds to below guideline values.

NATIONAL VALIDATION FRAMEWORK FOR WATER RECYCLING SCHEMES

Validation of the unit processes within a treatment train to show compliance with the overall performance requirements is important for any water recycling scheme.

There is currently no consistent approach to validating technology across Australia, despite it being a requirement of the AGWR. As a result, validation of identical or similar technologies is often replicated in our States and Territories; the only State to have published its own formal validation guidelines is Victoria (Department of Health 2013) and these have different requirements and methods of interpretation to, for example, New South Wales (Williamson 2013).

This 'difference' often results in plant commissioning taking longer and costing more, regulators having unnecessary duplication of work in reviewing validation reports and results in the potential for different States/Territories ending up with different validation results for the same treatment technology.

The Australian Water Recycling Centre of Excellence (AWRCE) addressed this need for a 'National Validation Framework for Water Recycling Schemes' across all States and Territories in its Strategic Research Plan (AWRCE 2012) and it has funded a project to develop such a framework, an initiative supported by utilities, regulators, and the private sector that service the water recycling industry, including operators, equipment suppliers and consultants.

The objectives of this 'National Framework' are as follows:

- Protect the health of the public and the environment.
- Support the AGWR which require treatment processes to be validated.
- Provide independent endorsement of technologies and processes.
- Ensure validation is consistent across all States and Territories in Australia.
- Ensure the validation process is transparent.
- Provide a mechanism for recognising validation carried out overseas, or as part of an international programme.

This project is proceeding in two stages:

- *Stage 1*, which is now complete, included consultation with industry and the Federal Government to establish their needs and concerns; a review of current and emerging techniques for validating treatment processes; identification of knowledge gaps and the design of a workable and accepted framework.
- *Stage 2*, which is in progress, includes research into some of the more important knowledge gaps identified in Stage 1, such as membrane bioreactors, pathogen removal by ozone and virus removal through RO, and the development of a suite of validation protocols for use by industry. This stage is due to be completed by June 2015.

VALIDATION OF THE GOREANGAB RECLAMATION PLANT (GRP), WINDHOEK

Non-treatment principles adopted at the GRP

The plant employs multiple barriers, including treatment-based, non-treatment-based, and operational barriers, to ensure adequate product water quality. Treatment barriers are defined as 'continually present systems that reduce the undesired substances in the water to an acceptable level' (du Pisani 2006). The non-treatment barriers include the following:

- Thorough policing and diversion of trade wastes to a separate treatment plant.
- Monitoring at inlet and outlet of the wastewater treatment plant (WWTP), allowing action to be taken before the water reaches the reclamation plant.

- Extensive monitoring of drinking water quality.
- Blending with other waters such that reclaimed water accounts for no more than 35% of the community's drinking water supply.
- A persistent and active community interaction programme.

In addition, plant management concentrates on rigorous monitoring and the plant operates under ISO and HACCP accreditation. Priority is also given to training and motivation of operating staff as well as funding salient research programmes (Iiputa *et al.* 2008).

The number of barriers in place for individual parameters varies as follows (du Pisani & Menge 2011):

- Three barriers for microbiological pollutants.
- Two barriers for physical and organoleptic parameters.
- Four barriers for trace organics and disinfection by-products.
- One barrier for critical parameters with no public health risk (e.g. stability).

It is concluded that this summary of the principles adopted at the GRP is similar to the Key Principles of the AGWR, as identified above.

Treatment barriers at the GRP

Quantitative microbial risk assessment

A QMRA was carried out for the GRP in 2011 by students from the Chalmers University of Technology in Gothenburg, Sweden (Ander & Forss 2011). This work was based on comparing identified risk levels with an acceptable health based target of 10^{-4} (1 in 10,000) annual probability of infection, a value similar to that adopted in the USA (Regli *et al.* 1991).

The work assessed the risk of infection caused by *Norovirus, Giardia* and *Cryptosporidium*, with *Escherichia coli*, *Clostridium perfringens* and *Somatic coliphages* being used as 'indicator organisms'. The latter three organisms are included in the sampling and monitoring programme in place at the plant.

The QMRA was carried out for two operational scenarios: *optimal operation* that was defined as operation without any disturbances or failures, and 'sub-optimal operation' that was defined as operation when there is a process failure or some other kind of process disturbance that decreases the overall plant's performance.

Conclusions drawn from this study were as follows:

- Of the three microorganisms evaluated, *Cryptosporidium* posed the greatest risk for both optimal and sub-optimal operation.
- Under optimal operating conditions, the probabilities of infection by *Norovirus, Giardia* and *Cryptosporidium* were acceptable, i.e. $<10^{-4}$.
- With the 95th percentile concentration and under epidemic feedwater levels, the risk of infection by *Cryptosporidium* was not acceptable.
- Consideration should be given to installing a UV disinfection stage to reduce this risk.

Removal of pathogens through the plant

The plant's routine sampling and monitoring programme includes analysing the removal of nine microorganisms across the plant (i.e. from feedwater to finished water) and Table 2 summarises the LRVs achieved over the period January 2006 to June 2007 (Menge *et al.* 2009).

It will be appreciated that the LRVs presented in Table 2 are those that were 'actually' achieved over the specified period and that they would be lower than those that could be claimed through a plant validation exercise, as is outlined in the above referenced QMRA study and as is required in the Australian Guidelines.

Validation against the AGWR

The flow schematic of the GRP is shown in Figure 1. The GRP draws feedwater from the Gammams WWTP in

Table 2 | Microorganisms monitored at the GRP

Microorganism	LRV	Microorganism	LRV
Heterotrophic plate count (HPC)	6.02	*Pseudomonas*	2.86
Total coliforms	5.26	*Clostridium* spores	4.94
Faecal coliforms	4.32	*Clostridium* viable	5.40
E. coli Tryptone[(a)]	2.01	*Somatic coliphages*	4.68
Faecal streptococci	3.67		

(a) *E. coli* is only measured in feedwater and sandfilter effluent.

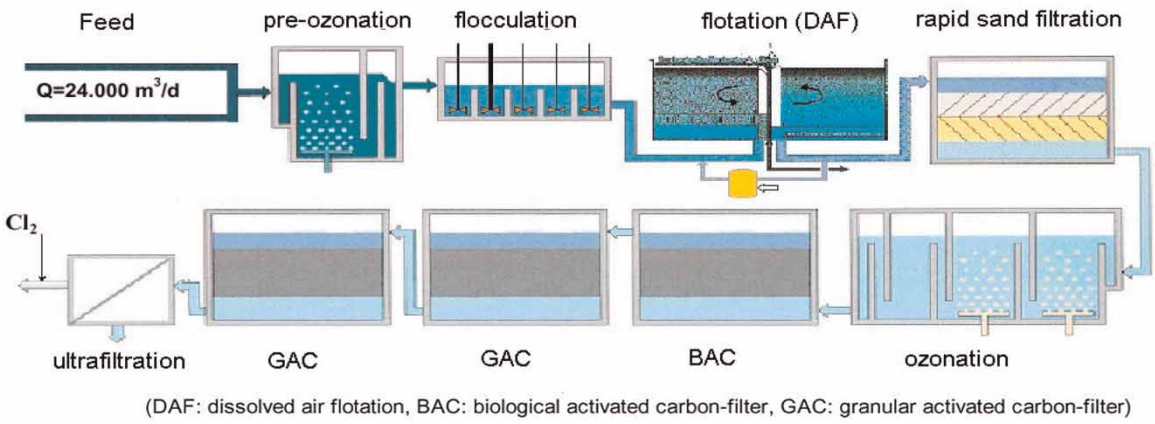

Figure 1 | Flow schematic of the GRP in Windhoek, Namibia.

admixture with water from the Goreangab Dam. The biological treatment stage in the WWTP is a biological nutrient removal activated sludge plant and the effluent from this plant passes through maturation ponds, with a 2 day hydraulic retention time, before entering the GRP. Since 2002, the feedwater has only been the Gammams WWTP effluent for more than 90% of the time and this has been taken as the starting point for the overall validation process in this paper.

In addition, the final water produced by the GRP is blended with other water such that it only comprises some 35% of the overall water supply.

Validation of the performance of the GRP against the AGWR for pathogen removal draws on a data base of plants validated in Australia, in which individual process units have been assigned LRV credits.

LRV credits that can be claimed for each of the process units that make up the treatment train are associated with key process design parameters – such as solids retention time in the WWTP (assuming an activated sludge type biological treatment process), hydraulic loading rate and media depth in the case of sand or dual media filtration, membrane flux and membrane integrity in the case of UF systems and CT value (residual concentration C × contact time T) in the case of chlorine and ozone. Other factors that play a significant role in identifying LRV credits are the water temperature and pH, particularly in the case of chlorination (Wati *et al*. 2013).

Table 3 summarises the key process design parameters in the plant and lists individual process unit virus, bacteria and protozoan LRV credits taken from the data base of validated Australian plants that incorporate similar process units having design criteria representative of those in place at the GRP (Law 2012; Mieog 2012; Cunliffe 2013; Department of Health 2013; Wati *et al*. 2013). Details of the associated Critical Control Points (CCPs) for the LRV credits are discussed in these references. Note that the credits listed for the BAC and GAC processes have been based on the work of Ander & Forss (2011) as such facilities have not, as yet, been validated in Australia and those for ozonation have been based on both the Melbourne work (Mieog 2012) and that reported by Paraskeva & Graham (2002) from the UK.

CONCLUSIONS

It is concluded that the non-treatment principles adopted at the GRP are similar to the Key Principles of the AGWR.

Further, the data drawn from plants validated in Australia, together with results from the experience of others with pathogen removal through the ozonation, BAC and GAC stages in wastewater applications, tend to confirm the conclusions drawn from the QMRA work of Ander & Forss (2011), that there could be a risk of infection by *Cryptosporidium* under *some* operating conditions. However, blending the GRP water with other water prior to consumption does reduce this apparent risk.

It should be noted that if cognisance is taken of the fact that viable infectious oocysts can be less than 50% of the 'total' number (Cunliffe 2013) and if the daily consumption

Table 3 | LRV credits across the GRP

Unit process	Process design parameters	*Virus LRV credit*	*Bacteria LRV credit*	*Protozoa LRV credit*
Gammams WWTP	BNR (long SRT)	0.5–1.0	1.0	0.5
Pre O_3 and Coag/DAF[(a)]	Pre-O_3 dose: 3 mg/L Contact Time: 3 min Coag Chem's: $FeCl_3$, HCl, polyelectrolyte DAF SLR: 4 $m^3/m^2/h$	Note (a)	Note (a)	Note (a)
Dual media filtration (DMF)	Rate: 6 m/hr Anthracite: 0.7 m (ES 1.3) Sand: 0.7 m (ES 0.7)	1.5	1.5	2.0
Ozone	Dose: 12 mg/L mg O_3/mg DOC: 1.1 Contact Time: 24 min CT: 12 mg/L/min	4.0	4.0	(>0.6[(b)]) 1.5–2.0[(c)]
BAC[(d)]	EBCT: 10 min minimum Bed Depth: 1.5 m	Note (d)	Note (d)	Note (d)
GAC	EBCT: 20 min minimum No of Stages: 2 Bed Depth: 1.5 m	*0.4*	*1.7*	*0.9*
UF	Flux: 70 L/m^2/h Recovery: 92%	2.5–3.0	3.0–3.5	3.0–4.0
Chlorination	Free Chlorination Contact Time: 1 h nom CT: 27 mg/L/min pH: 7.8–8.2 Temp: 15–20 °C	4.0	4.0	0.0
Total LRV credits – *AGWR default LRVs in brackets*		**12.4–13.9 *(9.5)***	**15.2–15.7 *(8.1)***	**7.9–9.4 *(8)***

(a) LRVs included in DMF values.
(b) Mieog (2012).
(c) Paraskeva & Graham (2002).
(d) LRVs included in GAC values.
BNR = Biological Nutrient Removal, SRT = Solids Retention Time, SLR = Surface Loading Rate, ES = Equivalent Size, DOC = Dissolved Organic Carbon, EBCT = Empty Bed Contact Time.

of water is reduced to 1 L/person/day (in lieu of the 2 L/person/day adopted in the AGWR), the overall LRV required for *Cryptosporidium* oocysts reduces from 8.0 to 7.4.

Further the LRVs tabulated have been drawn from plant validation results in Australia as well as results reported from elsewhere and as such, the results and conclusions should be viewed as 'indicative' rather than 'definitive'.

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