Validation of high rate algal ponds as an efficient wastewater treatment option to improve public health in rural communities

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Establishing performance of high rate algal ponds

South Australian rural communities commonly employ on-site systems for their residential wastewater treatment, e.g. septic tanks. Treated effluent is disposed of via sub-surface drainage or a 'soakage trench', however, public health and environmental issues arise, which are associated with various soil conditions and proximity to surface watercourses. Contamination of shallow bores used as potable water sources may occur where rapid infiltration of effluent through permeable sandy soils leads to groundwater contamination with pathogens and nutrients. In contrast, clay soils with low permeability may cause surface pooling of treated effluent, resulting in greater exposure of resident adults, children and pets to potential pathogens. Surface watercourses used as potable water sources or for recreation may, also, be contaminated from run-off during periods of heavy rainfall. Community Wastewater Management Schemes (CWMS) are installed for communities where, following a survey (Box 1), the public health and environmental risks associated with on-site disposal are deemed unacceptable. CWMS retain the on-site treatment system, however, the disposal trench is disconnected and the treated liquid phase is reticulated to a centralised treatment facility. In 2013, a total of 172 CWMS, of which 90 incorporated waste stabilisation ponds (WSP), were operated by 45 district councils, which - via 63,000 connections - treat wastewater from approximately 180,000 persons or 15% of the population of South Australia.

WSP systems are preferred where land area permits, since in rural communities there is limited expertise available to manage, operate and maintain electro-mechanical wastewater treatment plants, and there is an increasing awareness of issues associated with energy consumption and attendant greenhouse gas emissions.

Since their inception in 1962 the CWMS guidelines for the design of incorporated WSPs draw upon the work of Marais & Shaw (1961) for the management of microbial hazards. Current design criteria (Local Government Association of South Australia (LGA SA), undated) for CWMS WSPs assume dry weather flow (DWF) of 140 L capita d^{-1}, 50 g BOD_5 $capita^{-1}$ d^{-1} equivalent to 360 mg BOD_5 L^{-1}. The recommended lagoon configuration comprises 5 cells each with a length:width ratio of 2:1 and a depth of 1.2 m. The first facultative pond is required to have a theoretical hydraulic retention time (THRT) of 36d while the remaining four, in series maturation ponds, are required to each have a THRT of 7.5d – a total recommended THRT of 66d. This necessitates a large surface area, equivalent to 7.7 m^2 $capita^{-1}$ with significant attendant capital costs for construction. Where available land is restricted, this increases pressure on local councils to install the less preferred electro-mechanical systems.

High rate algal ponds (HRAP) potentially offer a more efficient, similarly pond-based, natural wastewater treatment option, with a smaller footprint and reduced evaporative losses. In 2005, we were successful in obtaining approval to construct and operate a research-demonstration HRAP at the Kingston on Murray CWMS. The HRAP comprises a 250 m^2 single pass raceway (5 m wide x 30 m long), capable of operation at depths between 0.3 - 0.5 m (Plate 1). A paddlewheel circulates the wastewater at a surface velocity of 0.2 m s^{-1}.

The Kingston on Murray township within Loxton Waikerie District Council comprises residential properties, a school and a backpackers hostel. The estimation of design values for DWF is an emerging issue for unsewered communities. Using current design criteria (LGA SA, undated) the estimated DWF is 60 m^3 d^{-1} for CWMS, however upon commissioning the actual DWF was only 12 m^3 d^{-1}.

The project compared the effluent treatment performance of the HRAP operated at Kingston on Murray with a CWMS WSP system; determined the optimum operating conditions to maximise HRAP performance and provided validated design criteria for HRAP operation in CWMS in South Australia. It also demonstrated that the HRAP produced twice as much treated effluent for beneficial reuse.

Box 1. CWMS implementation survey

Public health criteria

- Population trajectory at recent census
- Likely impact of the existing soakage trench arrangements on the health and wellbeing of residents and visitors within the town
- Allotment size, typical soil type, topography (slope), climatic conditions (annual rainfall), groundwater (depth to unconfined aquifer), notices of associated insanitary condition (issued, warnings and observations) over previous 12 months, frequency of residential uncontrolled pump out of septic tanks (gardens, roadway etc.), potable water source (reticulated or bore) and evidence of any potable bore water contamination

Environmental criteria

- Allotments within a flood plain, percentage within the 1 in 20 year flood plain; within a water storage catchment zone, within 200 m of the ocean or watercourse
- Water reuse potential: percentage of effluent to be, used for new irrigation, to be used to replace existing mains water
- Any issues raised by the EPA regarding septic tank performance

Economic criteria

- An indication of economic benefits that may result from an improved effluent disposal system.Increased land value estimated number of new residential allotments able to be created by subdivision
- Any other business opportunities able to be created (eg, trade waste disposal, aquaculture)

Social/community criteria

- Community or social benefits that may arise as a result of an improved effluent disposal system; Increase in population in the peak holiday season; effluent currently discharges into the environment in an area used for recreation, tourism and aquaculture
- Community suppourt for the scheme

To be included in CWMS, alternate treatment systems require approval of design guidelines from the South Australia Department of Health, Wastewater Management Group (DoHWMG). The approval process is consistent with the Australian *National Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)* (NRMMC, 2006). The guidelines employ the concept of disability-adjusted life years (DALYs) with the tolerable risk adopted at 10^{-6} DALYs per capita per year, equivalent to an annual risk of diarrhoeal illness of 1 per 1000. Health-based targets are those that must be met to ensure that the tolerable risk is not exceeded. Health-based performance targets to manage microbial hazards in treated wastewaters intended for various uses are derived within the guidelines using the initial concentration of the target organisms and data relating the route, frequency of exposure and likely ingestion volume to derive $\log_{10}$ reduction values (LRVs). The guidelines also provide LRV targets for specific end uses of treated wastewater. The treated wastewater from CWMS is most commonly reused to irrigate non-food crops, typically woodlots. The target LRVs for this reuse application for enteric organisms are 4.0 for bacteria, 5.0 for viruses, 3.5 for protozoa, with an additional treated wastewater quality objective of a median value of $<10^4$ *Escherichia coli* 100^{-1} mL (NRMMC, 2006).

Plate 1. HRAP at Kingston on Murray

The guidelines require knowledge of surrogate indicators of bacterial, viral and protozoan pathogens following passage through components of a wastewater treatment train. An independent National Association of Testing Authorities (NATA) accredited laboratory was required to perform the collection of wastewater samples and microbiological analysis. This requirement imposes significant logistical issues on new systems for application in remote rural communities; Kingston on Murray is 500 km return from the NATA accredited, Australian Water Quality Centre's (AWQC) analytical laboratory in Adelaide.

Pathway to validation

Initially, at the request of the DoHWMG, the Flinders University data from the research evaluation (2010 – 2012; Buchanan, 2014) was independently reviewed by AWQC. As a result, a second identical HRAP was constructed in series to the first and approval was sought from the DoHWMG for the HRAPs to be accepted as an alternative methodology to 'traditional passive lagoon [WSP] systems'. The DoHWMG required the validation to be conducted in winter (August – October, 2013) to reflect the worse-case scenario for a natural treatment system dependent upon temperature and light for disinfection. The two in series HRAPs were required to be operated over a period of 10 weeks, in a standard condition – depth 0.3 m, combined THRT of 10 days. Twenty inlet and 20 outlet 'grab' samples were collected from both HRAPs on Monday and Thursday each week to account for variations in daily flow and wastewater quality. The samples were transported on ice by bus and analysed by AWQC within 24h of collection. Concurrently, at the request of DoHWMG, environmental monitoring (photosynthetically active radiation, total UV irradiation (290 – 400 nm), air temperature, rainfall, humidity, wind speed and direction) and wastewater quality analyses, turbidity (NTU); suspended solids, BOD_5 and chlorophyll *a* were determined by Flinders University using *Standard Methods for the Examination of Water and Wastewater* (Greenberg et al., 1992).

E. coli, the surrogate indicator for enteric bacterial pathogens, was enumerated using the Colilert Quanti-Tray® following Australian Standard AS 4276.21-2005. The pathogenic enteric virus surrogate, F-RNA bacteriophage was enumerated using the methodology described in Appendix D of the USEPA UV Disinfection Guidance Manual (USEPA, 2006).

The requirement to provide an estimate of the LRVs for protozoan pathogens was problematic. The calculation of LRVs requires sufficient numbers of the target organism in the influent to ensure detection of survivors in the post-treatment effluent. In small rural communities, pathogenic protozoa excretion rates will be very low or non-existent making an LRV difficult or impossible to derive. One solution briefly considered was to 'spike' the influent with the target organism, however, the cost of addition and subsequent detection of commercially available *Cryptosporidium* oocysts was prohibitive. Consequently, with the agreement of DoHWMG, aerobic spore-forming bacteria (ASFB) which have been used as surrogates for protozoa in drinking water treatment (Hijnen et al., 2006), were used as surrogates for the validation of the HRAP. They were enumerated following pasteurisation and filtration of the wastewater sample as described by Rice et al., (1996).

Over the period of the validation, the total insolation ranged from 10.5 to 27.4 MJ d^{-1}, the HRAPs water temperature from 9.9 to 20.3°C and turbidity was between 100 and 290 NTU. The inlet BOD_5 ranged from 68 to 262 mg BOD_5 L^{-1}.

The LRVs were equal to the $\log_{10}$ difference between the initial inlet wastewater parameters and final outlet values from the second in series HRAP. The LRV median, mean and 5th percentiles were calculated for each indicator for the 10 week validation period (Table 1). The LRVs recorded for ASFB were negative, indicating that more ASFB were in the treated effluent than the influent (ASFB, Table 1). Young et al., (2016), concurrently with the winter validation exercise, collected composite daily samples (0.00 am and 12.00 pm; 400 mL per sample time) of HRAP treated wastewater using refrigerated (1°C) auto-samplers (Avalanche Sampler, ISCO Ltd, USA). It was shown that ASFB were also present in wind-blown agricultural soils accumulated in proximity to the HRAP and that the numbers of ASFB in the treated effluent were related to the temperature of the wastewater in the HRAP, suggesting growth of ASFB (Young et al., 2016). The data showed that ASFB were unsuitable surrogate indicators for enteric, pathogenic protozoa in natural wastewater treatment systems. UVA and UVB play a major role in disinfection in natural wastewater treatment systems (Bolton et al., 2010). In HRAPs the shallow depth and mixing increases exposure of microorganisms to disinfecting wavelengths. In these conditions *E. coli* was accepted as an adequate surrogate for protozoa from which an LRV could be inferred (Young et al., 2016).

Outcomes of validation and recommended applications

The DoHWMG accepted the HRAP met the health based, LRV performance targets after considering the conservative, independent, winter determination of the HRAPs 5th percentile LRVs for *E. coli* and F-RNA coliphage together with the on-site controls in place for woodlot irrigation, e.g. exclusion of public during irrigation, extended buffer zones. Additionally, the treated wastewater quality objective of a median value of <10^4 *E. coli* 100 mL^{-1} was also met.

LGA SA published the DoHWMG approved, *Design Guideline for a High Rate Algal Pond (HRAP) as an Element in Wastewater Treatment Trains*, in December 2015. Initially, the guideline approved two configurations for HRAP incorporation into CWMS. The first was considered an option for existing systems requiring an upgrade and comprised a single HRAP receiving treated septic tank liquid phase followed by subsequent treatment, e.g. traditional 4 cell, in series maturation ponds. The second configuration replaced the current 5 cell facultative – maturation pond series with two HRAPs operating in series, each operating at 0.3 m and 5d THRT, the first receiving septic tank treated liquid effluent with the treated effluent gravity feeding into the second HRAP. Subsequently, DoHWMG after interogating the long term data set acquired by Flinders University accepted that a single HRAP operated between depths of 0.3 and 0.5 m at a 10d hydraulic retention time met the health-based performance targets. The design guideline was ammended September 2016 to reflect this new configuration. The guidelines also include engineering drawings as examples of construction. The guidelines also note that "*each design must be engineered to suit the particular application, and each completed design is subject to approval by the [South Australian] Department for Health and Ageing*".

Table 1. Summary statistics of LRVs for surrogate indicators of enteric bacteria, viruses and protozoa achieved in winter by HRAPs operated at 0.3 m depth and combined THRT of 10 d

	E. coli LRV	F-RNA LRV	ASFB LRV
Median	2.90	2.08	-0.20
Mean	3.30	2.32	-0.05
StdDev	1.28	0.74	0.37

The case study also resulted in a recommendation regarding influent addition to ensure consistent treatment performance. Our modelling showed that the disinfection performance of the HRAPs was improved if the influent addition was continuous at flow rates equivalent to those required to achieve the THRT. Septic tank effluent in CWMS is reticulated to a collection sump from which it is pumped intermittently to the lagoons. This leads to 'pulse' loading of the HRAPs adversely affecting disinfection. If continuous loading is not possible, the guidelines indicate that no more than 4% of the pond volume should be introduced over a period shorter than 4% of the residence time – the '4% rule'. Helminth infections are not endemic in most parts of Australia (NRMMC, 2006), however, where treated water can be accessed by stock, a minimum 25 days' total treatment time is required - 10d HRT in the HRAP and an additional 15d storage pond time is required to ensure die-off of helminths.

There are few published validations of natural wastewater treatment systems in Australia. These systems are often in rural or remote locations making the validation logistically challenging. We have used portable, refrigerated, automated samplers throughout our research at Kingston on Murry and believe their application, with suitable controls, could be more widely employed in validation studies. There is clearly a need to identify a suitable surrogate indicator for protozoa in natural treatment systems, dependent upon light and temperature for disinfection, or more definitive determination of the relationship between *E. coli* and pathogenic protozoa in these systems.

The significant outcome of this case study was the regulatory approval of HRAPs for wastewater treatment which resulted in the publication of design guidelines for consultant engineers, which we believe to be unique. The application of HRAPs for wastewater treatment in rural communities reduces the surface area requirement from 7.7 m^2 $capita^{-1}$ to 2.8m^2 $capita^{-1}$ when operated at 0.5 m depth. This significantly reduces the capital cost for pond construction. Furthermore, the reduction in THRT from 66d for the traditional 5-cell WSP to 10d for the HRAP significantly reduces evaporative losses providing more treated wastewater available for beneficial re-use.

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