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Wastewater treatment by a modular, domestic-scale reedbed system for safe horticultural irrigation

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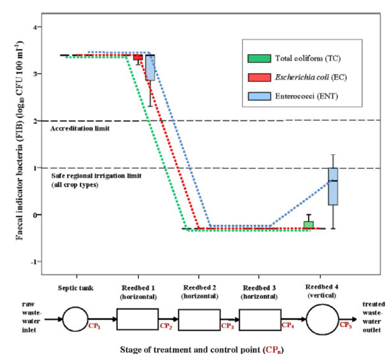
HIGHLIGHTS

- Wastewater treatment in the reedbed system produced water suitable for food crop irrigation.
- The modular design facilitated monitoring and management of process at control points.
- The system eliminated the need for chlorination and provided additional microhabitat.

GRAPHICAL ABSTRACT



Faecal Indicator Bacteria (FIB) removal by stage of treatment (arithmetic zero indicated on semi-log graph by means of low arithmetic constant (0.5) (McDonald, 2009)).

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ABSTRACT

The aim of the study was to assess the sequential treatment performance of a commercial, domestic-scale modular reedbed system intended to provide safe horticultural irrigation water. Previously only mechanical treatment systems involving forced aeration with subsequent disinfection, usually by tablet-chlorination, had been accredited in Australia. The modular design of the hybrid, subsurface-flow reedbed system offered 5 control points where monitoring and management of the treatment train could be carried out. Ten chemical parameters (chemical and biochemical oxygen demand, total organic carbon, total Kjeldahl nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, total nitrogen, dissolved oxygen percentage saturation and suspended solids) and 4 microbial parameters (total coliform, *Escherichia coli*, enterococci and *Clostridium perfringens*) reached satisfactory levels as a result of the treatment process. Health requirements for safe horticultural irrigation were met by the outlet of the second reedbed, providing a high level of treatment-backup capacity in terms of the remaining 2 reedbeds. This suggested that chlorination was a redundant backup precaution in treating irrigation water to the acceptable regional guideline level for all horticultural uses, including the spray irrigation of salad crops eaten raw.

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1. Introduction

The treatment performance of medium to large scale wetland systems receiving urban and industrial wastewater has been extensively studied in the past 30 years with over 100 publications on specific aspects of the treatment train and final water quality (Vymazal, 2014). Relatively little has been published, however, on the progressive treatment performance of hybrid, domestic-scale units, designed to produce recyclable effluent for home horticultural irrigation.

The aim of the study was to assess the treatment train in a prototype of a commercial system constructed at the Macarthur Centre for Sustainable Living (MCSL) at Mt Annan in Sydney's southwest, on which the domestic system later accredited by State health departments in Victoria and New South Wales (NSW) was based. The assessment was carried out using standard operational and health parameters to enable comparison of this green technology with mechanised types of onsite and centralised treatment technologies, during the future production of improved accreditation and irrigation guidelines. The results would also inform the design and operation of such systems.

The imperative for domestic water recycling in Australia was emphasised by the millennium drought of 1991 to 2009 when extreme restrictions on the use of urban water supplies for garden irrigation were imposed (Hurlimann and Dolnicar, 2010; Van Dijk et al., 2013). At that stage most domestic onsite treatment was by traditional septic tank and soakaway, which failed to treat wastewater to an acceptable recycling standard. The risk associated with these systems became apparent in 1997 when 200 cases of hepatitis A resulted through the consumption of Wallis Lake oysters, contaminated by poorly monitored and managed septic tank systems (Conaty et al., 2000).

Local government response in many areas was to require a changeover to conservancy tanks with road transport to centralised treatment works, resulting in increased burden on existing facilities and an increased carbon footprint of settlement. At state level, there were calls for innovative onsite treatment designs to generate safe horticultural irrigation water. By 2010, NSW Health had approved 30 designs for small bioreactor systems with forced aeration and tertiary disinfection, 27 of which used sodium hypochlorite tablets. A tendency to overdose to compensate for imbalance in the hydraulic/organic loading ratio was subsequently identified, with a risk of additional disinfection byproduct burden to the environment (Dharmappa and Khalife, 1998; NSW Department of Local Government, 1998; Sun et al., 2009). A risk of aerosolization of pathogenic viruses during forced aeration was also possible (Heinonen-Tanski et al., 2009; Slote, 1976).

One alternative green technology system designed by Rootzone, Australia Pty. Ltd. based on a hybrid subsurface horizontal and vertical flow reedbed system was accredited in 2009. The system was based on add-on polypropylene liners to match hydraulic/organic loading, with gravity flow or solar pumping for reduced domestic carbon footprint. In addition, carbon would be sequestrated by reeds which could be cut for slow-breakdown applications such as mulching and frost protection. Chlorination of the final effluent was not an accreditation requirement although local government subsequently tended to ask for this, suggesting a need for research to place requirements on an informed footing (Natural Resource Management Ministerial Council et al., 2006; Australian and New Zealand Environment and Conservation Council, and Agriculture and Resource Management Council of Australia and New Zealand, 2000).

The paper discusses removals in the system in terms of a monitoring subset of 10 chemical and 4 microbial parameters relevant to operational performance and horticultural irrigation. Chemical parameters were chemical and biochemical oxygen demand (COD and BOD_5), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N) and total nitrogen (TN), dissolved oxygen percentage saturation (DO %sat) and suspended solids (SS). Microbial parameters were total coliform (TC), *Escherichia coli* (EC), enterococci (ENT) and *Clostridium perfringens* (CP). Parameters relevant to potential ecological disturbance such as metals, hydrocarbons, redox state of nitrogen, and other nutrients are to be discussed elsewhere. (American Public Health Association et al., 2005; Lazarova and Bahri, 2005).

2. Materials and methods

2.1. The reedbed system

The treatment train consisted of a septic tank followed by 3 horizontal, subsurface-flow reedbeds with a final vertical reedbed (Fig. 1). The modular arrangement facilitated collection of samples at 5 control points in the treatment train enabling progressive change in water quality with treatment stage to be studied. The standard 3000 L domestic septic tank with 1.9 m fluid depth provided primary treatment through anaerobic digestion with solids removal. Each of the horizontal 5.4 m^3 reedbeds was contained in a plastic polymer tray 3 m long by 2 m wide, filled to a depth of 0.9 m with a proprietary filter medium with a saturate hydraulic conductivity of 100 to 300 mm/h, silt content of about 1.5% and organic content of about 2.5%. Particulate size equated to sandy loam mixes used in reedbeds elsewhere. Inlet and outlet arrangements are shown in Fig. 2. These beds were intended to provide secondary and tertiary treatment, including nitrogen removal, through anaerobic conditions in the saturated zone and aerobic conditions in the unsaturated root zone above. The vertical subsurface-flow reedbed was contained in a 2.5 m diameter plastic polymer module, with 0.6 m of substrate above a 0.9 m deep gravel reaction zone, and surface sparge distributor as shown in Fig. 3. Here the filter medium was unsaturated, presenting aerobic conditions intended to continue in the reaction zone which was pumped out up to twice daily. While extra horizontal units in parallel were supplied to enable servicing or cope with system overload, these were not in use during the study. At the time of study the final effluent was only used for subsoil lawn irrigation given the exploratory nature of the project.

It must be emphasised that in green treatment systems a number of biochemical processes may be simultaneously occurring at each site, blurring the distinction between primary, secondary and tertiary treatment sites. The sampling point was the drainage chamber of each unit which also provided some degree of hydraulic flow control.

All reedbeds had been planted with seedlings of common reed (*Phragmites australis*) in early summer, the study being initiated 6 months later when the reeds had reached a stem median height of about 1.1 m in the primary reed bed, with contiguous root development across the root zone. On conclusion of the study 12 months later, the stem median height of the reeds was about 1.8 m.

The on-site system treated all black and grey water harvested from the following areas:

- A cottage with offices for 1 to 2 full-time staff, relaxation area for about 10 volunteers attending 1 to 2 days per week, kitchenette, toilet and washroom. No staff lived on the premises.
- A meeting venue accommodating meetings of 10–30 people on an approximately monthly basis with adjoining office for 4 to 5 full time staff, with a kitchen, 3 public toilets and a shower. During the research period the kitchen was not used for heavy catering. On open days there could be over 1000 visitors to the site during a 4 to 5 hour period, although turnover of visitors was estimated at 200 per hour, suggesting relatively short visits when minimal use would be made of the toilets. Correlation of daily hydraulic flow with number of people entering the site indicated a low relationship ($r = 0.27$), supporting this assumption.

While the Centre was not domestic in nature, hydraulic flows for the initial study period (2007–2008) gave a median daily input of 730 L day^{-1} with a range of 220 L to 2000 L day^{-1}, which equated