Design, construction and performance of a horizontal subsurface flow wetland system in Australia
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ABSTRACT

Malabugilmah is a remote Aboriginal community located in Clarence Valley, Northern NSW, Australia. In 2006, seven horizontal subsurface flow (HSSF) clusters consisting of 3 m x 2 m wetland cells in series were designed and constructed to treat septic tank effluent to a secondary level (Total Suspended Solids (TSS) < 30 mg/L and Biochemical Oxygen Demand (BOD₅) < 20 mg/L) and achieve > 50% Total Nitrogen (TN) reduction, no net Total Phosphorus (TP) export and ≥99.9% Faecal Coliform (FC) reduction. The wetland cell configuration allowed the wetlands to be located on steeper terrain, enabling effluent to be treated to a secondary level without the use of pumps. In addition to the water quality targets, the wetlands were designed and constructed to satisfy environmental, economic and social needs of the community. The wetland systems were planted with a local Australian wetland tree species which has become well established. Two wetland clusters have been monitored over the last 4 years. The wetlands have demonstrated to be robust over time, providing a high level of secondary treatment over an extended period.

Key words | aboriginal, constructed wetland, Melaleuca, paperbark

INTRODUCTION

Malabugilmah is an Aboriginal community located in Clarence Valley in Northern New South Wales, Australia, approximately 85 km north of Grafton. The village has a population fluctuating around 80 people, and consists of 17 houses and two community buildings. In 2006, seven horizontal subsurface flow (HSSF) constructed paperbark wetlands were built to treat septic tank effluent from Malabugilmah to a secondary level before reuse onto a football field. Constructed wetlands provide an effective low cost and low maintenance system for the treatment of domestic sewage of rural communities (Coleman et al. 2001; Manios et al. 2003). HSSF constructed wetlands have been used to treat a variety of wastewaters worldwide (Vymazal et al. 2006). They have the added benefit of reducing human contact with wastewater, avoiding the breeding of mosquitoes, and are less climate and temperature sensitive when compared to free water systems (US EPA 2000; Kadlec & Wallace 2008; Kadlec 2009). Melaleuca (‘paperbark’) trees were planted in the wetlands on the basis of their demonstrated ability to thrive in nutrient-rich and waterlogged conditions (Bolton & Greenway 1997) and excellent pollutant removal capability (Bolton & Greenway 1999; Bolton 2012).

The constructed wetlands were built to improve detrimental human and river health impacts caused by the previous failing sewage system. The treatment system was designed to meet Australian secondary treatment standards (AS/NZS:1547 2000) with target water quality parameters <20 mg/L Biochemical Oxygen Demand (BOD), <30 mg/L Total Suspended Solids (TSS), and design goals were set for ≥50% Total Nitrogen (TN) removal, ≥0% Total Phosphorus (TP) removal (i.e. no phosphorus export) and ≥99.9% removal of Faecal Coliforms (FC), within a 12 month establishment phase. The wetland project additionally aimed to satisfy the social, economic and environmental needs of the community. The community was engaged at all stages of planning and design, and 14 community members were employed and received on-the-job training during construction. Community members continue to be trained and employed to operate and maintain the sewerage treatment system.

DESIGN AND CONSTRUCTION

In 2004, Ecoteam convened a brainstorming session with the Malabugilmah community which identified a number...
of key issues. A failing sewage system had resulted in poorly treated effluent being discharged into the local swimming hole. These issues were related to pump failure, inappropriate creek discharge, poor treatment and flooding of the oxidation pond system at the community. This resulted in serious health risks for the community and environment. The community additionally identified that the lack of sport and recreation facilities, and limited access to education and training opportunities, caused social issues, which were compounded by the remote location of Malabugilmah. Through this brainstorming process the concept of a treatment process using constructed wetlands and effluent reuse onto a football field was conceived, and a steering committee was formed. The high level of community engagement at all stages – including project concept, construction, and operation and maintenance – has given the community a high level of ownership and self-determination over their essential community infrastructure.

In 2006, Ecoteam was engaged to design and supervise the construction of the Malabugilmah wetland wastewater treatment system. During the construction phase, 14 community members were employed on a full-time basis during the project. Construction of the treatment wetlands, football field, and subsurface irrigation system took 6 months to complete on a budget of AU$499,000. On-the-job training and accreditation for all community employees was provided by Technical and Further Education (TAFE) NSW. All employees gained valuable skills and around half of the community participants received further employment as a direct result of the work experience provided by the programme.

**HSSF wetland system**

The Malabugilmah wetland treatment system was designed to treat septic tank effluent to a secondary level for 80 p.e. (population equivalent), representing an estimated daily flow of 11.6 kL. The treatment system is decentralised, and consists of seven treatment units (‘wetland clusters’) located throughout the village, each containing from 3 to 12 wetland cells in series which receive septic tank effluent from one to four houses or community buildings. This configuration allowed the wetland to be located on steeper terrain, enabling effluent to be treated to a secondary level without the use of pumps. Wetland clusters were built using prefabricated polyethylene wetland cells (3 m length × 2 m width × 0.9 m depth) which are more durable than polyethylene liners and are readily available in Australia for use in domestic systems. In 2012, some wetland cells were replaced with concrete cells due to fire damage.

Wetland tubs are filled with 20 mm gravel and are planted with *Melaleuca* ‘papercork’ tree species. The inlet of each wetland contains a 150 mm slotted distribution pipe, and the outlet sump consists of slotted 500 mm PVC pipe. An emergency overflow pipe conveys effluent to downstream cells in case of hydraulic overloading. Each wetland cell contains a de-sludging system to flush accumulated sludge from the inlet pipes by opening an endcap extending through the wall of the cell. The water level is maintained 10 cm below the gravel surface. The first cells of each wetland cluster are filter cells which capture the majority of the sediment, and are designed to have gravel removed and replaced every 3–5 years. Each wetland cluster is fenced with warning signs due to their proximity to an urban environment. Figure 1 below shows a typical configuration of a wetland cell.

**Melaleuca trees**

The HSSF constructed wetland cells were planted with *Melaleuca* tree species (‘papercork’ trees) at a density of 4 trees/m². Papercork tree species used in the wetlands were *Melaleuca alternifolia*, *M. linearifolia*, *M. quinquenervia*, *M. leucadendra*, *M. halmaturorum*, *M. bracteata*, *M. salicina* and *M. viminalis*. Paperbark wetlands were chosen for the Malabugilmah constructed wetlands for a number of reasons: (i) paperbark trees thrive in constructed wetlands in subtropical Australia (Bolton & Greenway 1997, Bolton 2012); (ii) constructed paperbark wetlands have excellent pollutant removal capability (Bolton & Greenway 1999, Bolton 2012), and (iii) waterlogged paperbark trees flower several times per year, providing aesthetic qualities.

*Melaleuca* are Gondwanan tree species from the Myrtaceae family which evolved in wetlands on the margins of tropical rainforests (Barlow 1988). Many species are endemic to wetlands and riparian zones throughout Australia and South East Asia and exhibit exceptional tolerance of waterlogging, salinity and nutrients (Van der Moezel & Bell 1990; Winning & Clarke 1996). A number of *Melaleuca* tree species contain spongy, papery bark, composed of cork cells, giving paperbark trees their common name. The trees have become well established in the wetland systems and have been easy to maintain.

*Melaleuca* trees after 3 years of growth provide several times per year, providing aesthetic qualities.
**Management and maintenance**

The Malabugilmah sewage treatment system has been operated and maintained by Ecoteam since 2008 through the NSW Aboriginal Communities Water and Sewage Program which provides funding for the maintenance, operation and repair of water supply and sewerage systems in 61 eligible Aboriginal communities in NSW. Ecoteam employs several local community members to maintain the community water supply and sewerage systems, supported by bi-weekly visits from a Senior Ecoteam Operator. Two Community Water Managers are undertaking traineeships in Water Industry Operations. The wetland systems have relatively low operation and maintenance requirements compared with mechanised treatment systems in Aboriginal communities.

**METHODS**

Effluent from the inlet and outlet of two wetland clusters (Cluster 2 and Cluster 5) has been sampled between 2009 and 2012. Cluster 2 consists of 10 wetland cells with a
total wetland surface area of 60 m², while Cluster 5 has five wetland cells with a total surface area of 60 m². Cluster 2 was designed for four houses with an estimated water usage of 2,900 L/day, assuming 20 occupants. Cluster 5 was designed for two houses with an estimated water usage of 1,450 L/day. Both wetland clusters have an estimated hydraulic retention time (HRT) of 6.5 days.

Sampling was achieved by taking effluent from an inspection opening located before the first cell and the outlet sump of the last wetland cell in each cluster. Samples were taken using a submersible sample pump and were held on ice and taken to the Environmental Analysis Laboratory (EAL) in Lismore. Samples were analysed for a range of parameters; however, this paper will focus on TSS, BOD₅, TN, TP and FC. These parameters were specific design goals for the wetlands treatment system, which was required to achieve Australian secondary treatment outlet concentrations of <20 mg/L TSS and <30 mg/L BOD₅. The Malabugil-mah wetlands were designed to achieve Australian secondary treatment standard concentrations of <20 mg/L TSS and <30 mg/L BOD₅. Inlet concentrations of TSS ranged from 70 to 332 mg/L, while outlet concentrations ranged from below detection limits up to 4 mg/L. The two wetland systems had an average TSS outlet concentration of 2 mg/L and an average removal efficiency of 98.6%, and in all cases the wetlands easily achieved their design targets of <30 mg/L of TSS. The primary mechanism for suspended solids removal in horizontal flow wetlands is through settling and flocculation of colloidal particulates and gravity sedimentation (Vymazal & Kröpfelová 2008).

Inlet concentrations of BOD₅ ranged from 88 to 247 mg/L, while outlet concentrations were between 1.2 and 24 mg/L, averaging 10 mg/L at the outlet, which is well below the design target.

The two wetlands had an average BOD₅ removal of 94%. The wetland achieved the design treatment targets of <20 mg/L BOD₅ in all but one case (C5 during November 2011), where the outlet concentration was recorded at 24 mg/L. This declined to 11 mg/L BOD₅ outlet concentration in the following year. BOD is a measure of carbon content within the wastewater. The aerobic removal of carbon compounds is via heterotrophic oxidation, while anaerobic digestion is also an important removal mechanism in HSSF wetlands (Kadlec & Wallace 2008). The wetlands demonstrated they were capable of performing secondary treatment for an extended period of time. Figures 4 and 5 overleaf show the inlet and outlet concentrations and removal percentage of TSS and BOD₅ in both clusters sampled over the 4-year study period.

**Total nitrogen and total phosphorus**

The wetland systems were designed to perform to Australian secondary treatment standards (<20 mg/L TSS, <30 mg/L BOD₅), but had additional design goals of a 50% reduction...
in nitrogen and no net phosphorus release. Inlet TN concentrations ranged from 37 to 61 mg/L in both wetland clusters during the sampling period, while outlet TN concentrations ranged from 16 to 37 mg/L with an average outlet concentration of 24 mg/L. During the sampling period the wetland clusters had an average TN removal efficiency of 48%; the 50% nitrogen removal target was not achieved for all sample periods. Similar HSSF wetland systems being used in NSW, Australia, have achieved average nitrogen load reductions of between 38 and 66% (Davison et al. 2001; Bayley et al. 2003). TN removal in subsurface wetlands is attributed to nitrification and denitrification processes within the wetlands (Bayley et al. 2003).

Inlet phosphorus concentrations ranged from 5.0 to 10.5 mg/L during the sampling period, while outlet concentrations ranged from 3.8 to 7.6 mg/L with an average outlet concentration of 4.6 mg/L. During the sampling period the wetland clusters had an average phosphorus removal efficiency of 29%. In one instance (2011 Cluster 2) the wetlands were noted to export phosphorus. Phosphorus is uptaken by plants and converted to biomass, adsorbed onto substrate media and by accreted sediments in constructed wetlands. These storage pathways have finite capacity, which reduces the amount of phosphorus that can be retained. Generally phosphorus adsorption is influenced by the amount of calcium, aluminium, iron and organic matter found in the substrate. Once the retention capacity has been exhausted, phosphorus may be exported from the wetland (Vymazal et al. 2006; Kadlec & Wallace 2008). Gravel is a useful substrate in HSSF wetlands due to its high hydraulic conductivity; however, it has a relatively low phosphorus adsorption capacity (Vymazal & Kröpfelová 2008). Phosphorus outlet concentrations were observed higher than the inlet concentration during the sampling period. This is an indication that the gravel substrate reached its phosphorus retention capabilities.

Figures 6 and 7 present total nitrogen and total phosphorus concentrations at the inlet and outlet of the wetlands and percent removal efficiency.

Faecal coliforms

The Malabugilmah wetland treatment system was designed with an additional target goal of ≥99.9% reduction in FC. FC concentrations were highly variable through the treatment train of the wetland systems. Inlet concentrations of FC ranged from $9.60 \times 10^4$ to $2.16 \times 10^7$ colony-forming units (c.f.u.)/100 mL, while outlet concentrations ranged from $2.50 \times 10^2$ to $5.40 \times 10^4$ c.f.u./100 mL. The system achieved an average log reduction of 2.1 and the average removal of FC was 99.5%, which was below the treatment target of 99.9% removal. Table 1 presents the inlet and outlet concentrations, removal efficiency and log reductions of FC of each sampling date taken from both wetland clusters during the study period. Wetlands are effective at pathogen reduction of wastewater. The presence of plants has a positive effect on pathogen reduction in HSSF wetlands (Kadlec & Wallace 2008).

CONCLUSION

This study demonstrated that HSSF constructed paperbark wetlands are capable of treating septic tank effluent to a secondary level over an extended period, and can be a robust and reliable means of sewage treatment in remote communities. The cell-based design allowed for gravity flow on the steep site and secondary treatment was consistently...
achieved without the use of pumps or electrical components. A gravity-flow HSSF wetland can meet guideline objectives and have the added benefit of becoming a community asset which has aesthetic values. Although the wetlands did not always achieve design goal outlet concentrations of TN, TP and FC, the wetland clusters sampled still performed a reasonable level of treatment and reduction of these parameters.

The constructed wetlands were planted with local *Melaleuca* tree species, which were demonstrated to be a robust wetland plant capable of performing in wetlands designed for secondary treatment. The wetlands were designed and constructed to satisfy environmental, economic and social needs of the community. The community was involved in all stages of the design, construction and maintenance of the wetland treatment system. The low-tech nature of wetland systems allowed community participation during construction and continuing maintenance of the system. For these reasons wetland treatment systems are ideal for application in remote areas of Australia.

### REFERENCES


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*Table 1* | Inlet and outlet concentrations, removal efficiency and log reductions of faecal coliforms tested over the last 4 years in the study wetland clusters

<table>
<thead>
<tr>
<th>Sampling station and date</th>
<th>Inlet (c.f.u. 100 mL)</th>
<th>Outlet (c.f.u. 100 mL)</th>
<th>Removal efficiency (%)</th>
<th>Log reduction</th>
</tr>
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<tbody>
<tr>
<td>2009 C2</td>
<td>2.34 × 10⁵</td>
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<td>2010 C2</td>
<td>9.60 × 10⁴</td>
<td>9.00 × 10¹</td>
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<td>2011 C2</td>
<td>3.60 × 10⁶</td>
<td>5.40 × 10⁴</td>
<td>98.50%</td>
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<tr>
<td>2012 C2</td>
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<td>2.00 × 10⁴</td>
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<tr>
<td>2009 C5</td>
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<td>4.00 × 10²</td>
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<td>Average</td>
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