Waste stabilization ponds and rock filters: solutions for small communities

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Abstract In temperate climates facultative ponds and rock filters (either unaerated or, if ammonia removal is required, aerated) are a low-cost but high-performance treatment system for small rural communities. Effluent quality is suitable for surface water discharge or, in summer, for restricted crop irrigation. In tropical climates anaerobic and facultative ponds and either unaerated rock filters or, if ammonia reduction is required, subsurface horizontal-flow or vertical-flow constructed wetland, can be used if the effluents are discharged to surface waters. However, if the treated wastewater is to be used for crop irrigation, then a 3-log unit pathogen reduction by treatment in anaerobic, facultative and single maturation ponds is required for both restricted and unrestricted irrigation, provided that, in the case of unrestricted irrigation, there are in place post-treatment health-protection control measures that together provide a further 4-log unit pathogen reduction.

Keywords Constructed wetlands; pathogen reduction; rock filters; waste stabilization ponds; wastewater reuse

Introduction
It is now well established in many countries, both industrialized and developing, that waste stabilization ponds (WSP) are a very suitable method of wastewater treatment for small sewered communities. What is not so well established, despite many years experience in the United States (O’Brien et al., 1973; Swanson and Williamson, 1980; Middlebrooks, 1988, 1995; US EPA, 2002), is that rock filters are equally suitable for ‘polishing’ WSP effluents (i.e. to remove algal solids and associated BOD). In contrast, constructed wetlands have been strongly advocated in the United States for this purpose (Kadlec, 2004).

WSP for small communities are designed in much the same way as those for larger populations. To illustrate this WSP systems are now designed for a typical small community in a temperate climate and for one in a tropical climate, using design temperatures of 8 and 20°C, respectively.

Temperate climates
A facultative pond loaded at 80 kg BOD per ha per day (i.e., 8 g/m² d) would be appropriate (Abis and Mara, 2003). Assuming a BOD contribution of 40 g per person per day in rural areas (Pujol and Liénard, 1990), the pond mid-depth area would be 5 m² per person. Such a pond produces an effluent complying with the UWWTD (Abis and Mara, 2003).

Effluent discharge to surface water
To produce a final effluent with a low suspended solids (SS) concentration (e.g. ≤30 mg/l) the facultative pond effluent is best treated in a rock filter. Early work in the US has shown that rock filters are as good as other ‘pond polishing’ technologies (such as constructed wetlands or intermittent sand filters) but much cheaper (Middlebrooks, 1995). Our work in the UK shows that a hydraulic loading rate (HLR) of 0.3 m³ of facultative pond effluent per m³ of gross rock filter volume day per day is suitable for the
production of ≤ 40 mg unfiltered BOD/l and ≤ 60 mg SS/l (95-percentile values) (Johnson and Mara, 2005; Mara and Johnson, 2006).

If the environmental regulator specifies a maximum ammonia concentration for the final effluent of 10 mg N/l or less, then the rock filter should be aerated (Johnson and Mara, 2005; Mara and Johnson, 2006) to provide the conditions for ammonia removal by nitrification. At an HLR of 0.3 d⁻¹ and an air flow rate of 20 l/min an aerated rock filter can produce an effluent with ~9 mg BOD/l, ~9 mg SS/l and ~7 mg ammonia-N/l (95-percentile values) throughout the year (Figure 1), consistently better than the effluent quality of an unaerated rock filter. Our experience with subsurface horizontal-flow constructed wetlands is that they produce a good quality effluent in summer, but not in winter (Figure 2).

The area of both aerated and unaerated rock filters (\( A_{rf} \)) is given by:

\[
A_{rf} = \frac{Q_i}{(HLR) \times D_{rf}} = \frac{0.2}{0.3 \times 0.6} = 1.1 \text{ m}^2 \text{ per person}
\]

where \( Q_i \) is the wastewater flow (taken as 0.2 m³ per person per day; British Water, 2005) and \( D_{rf} \) is the wastewater depth in the rock filter (taken as 0.6 m).

Thus the area of a primary facultative pond and a rock filter is 6.1 m² per person (i.e. around 8 m² per person overall).

**Crop irrigation in summer**

The effluent from the aerated rock filter contains < 1000 faecal coliforms (FC) per 100 ml, and often in summer < 100 per 100 ml (Mara and Johnson, 2006). Thus the effluent would

![Figure 1](https://iwaponline.com/wst/article-pdf/55/7/103/439603/103.pdf)
be suitable for restricted crop irrigation as the pathogen reduction, as indicated by this level of FC removal, would be more than the 2–3 log units required (WHO, 2006).

**Tropical climates**

In this case an anaerobic pond followed by a facultative pond would be generally used. At 20°C the design loadings on anaerobic and facultative ponds are 300 g BOD/m³ d and 250 kg BOD/ha d, respectively (Mara, 2004). Assuming a BOD contribution in the rural tropics of ~35 g/person d and a wastewater flow of 0.07 m³ per person per day, the anaerobic pond volume is 0.12 m³ per person (or, assuming a depth of 3 m, a mid-depth area of ~0.04 m² per person; the retention time is 1.7 days). With 60 per cent BOD removal in the anaerobic pond at 20°C, the facultative pond retention time is 12 d and its mid-depth area is 0.56 m² per person – i.e. a total mid-depth area of ~0.6 m² per person.

**Effluent discharge to surface water**

Prior to surface water discharge facultative pond efﬂuents can be treated in rock filters, subsurface horizontal-flow or vertical-flow constructed wetlands (the latter are preferred if ammonia removal is required). For rock filters an HLR of 0.5–1 m³ of facultative pond efﬂuent per m³ of gross rock filter volume per day should be used (Saidam et al., 1995; Mara et al., 2001; Neder et al., 2002). Assuming a wastewater flow of 0.07 m³ per person per day, an HLR of 0.75 d⁻¹ and a Dₜ of 0.6 m, the rock filter area is 0.16 m² per person. Thus the area of the anaerobic and facultative ponds and the rock filter is 0.76 m² per person (i.e. around 1 m² per person overall). Effluent quality can be estimated on the basis of 80 per cent BOD removal in the anaerobic and facultative ponds and 50 per cent in the rock filter – i.e. a cumulative BOD reduction of 90 per cent.

**Crop irrigation**

For agricultural reuse a 2–3 log unit pathogen reduction is required for restricted irrigation and a 6–7 log unit pathogen reduction for unrestricted irrigation (WHO, 2006). The 2–3 log unit pathogen reduction for restricted irrigation is achieved solely by treatment, but the 6–7 log unit pathogen reduction for unrestricted irrigation is best partially achieved by treatment and partially post-treatment health-protection control measures (the most commonly employed of these are given in Table 1).

*Restricted irrigation.* The reduction of *Escherichia coli* (used as an indicator for bacterial, viral and protozoan pathogens) occurring in the anaerobic and facultative ponds
can be estimated by the equations of Marais (1974):

\[ N_e = \frac{N_i}{(1 + k_{BT} \theta_A)(1 + k_{BT} \theta_F)} \]

where \( N_i \) and \( N_e \) are the number of E. coli per 100 ml of the raw wastewater and facultative pond effluent, respectively (\( N_i \) is taken as \( 10^7 \)); \( k_{BT} \), the first-order rate constant for E. coli removal, \( \text{d}^{-1} \) (\( = 2.6(1.19)^{T-20} \)), i.e. \( 2.6 \text{d}^{-1} \) for 20°C; and \( \theta_A \) and \( \theta_F \), the mean hydraulic retention time in the anaerobic and facultative pond, respectively, \( \text{d} \) (here, \( \theta_A = 1.7 \text{d} \) and \( \theta_F = 12 \text{d} \)). Thus \( N_e = 6 \times 10^4 \) per 100 ml. A single 3-d maturation pond would be required to reduce this to 7000 per 100 ml — i.e. to achieve a 3-log unit pathogen reduction (as indicated by the E. coli reduction from \( 10^7 \) to \( < 10^4 \) per 100 ml), so making the effluent safe for restricted irrigation using labour-intensive agriculture (WHO, 2006). In this case this series of an anaerobic, a facultative and a single maturation pond would be the most cost-effective solution.

Unrestricted irrigation. The 3-log unit pathogen reduction by treatment in the pond series developed for restricted irrigation would also be satisfactory for unrestricted irrigation, provided that there were a combination of post-treatment health protection measures which together gave a 4-log unit pathogen reduction, such that the overall pathogen reduction would be 7 log units. This additional 4-log unit pathogen reduction could be realised by, for example, a 2-log unit reduction due to pathogen die-off and a 2-log unit reduction due to produce disinfection; by the drip irrigation of high-growing crops (4-log unit reduction); or by the drip irrigation of low-growing crops (2-log unit reduction), a 1-log unit reduction due to die-off and a 1-log unit reduction due to produce washing in clean water (Table 1). Wastewater treatment to achieve a pathogen reduction of >3 log units would not be cost-effective, especially as low-cost drip irrigation equipment is now available (Polak et al., 1997; Intermediate Technology Consultants, 2003).

Conclusions

- In temperate climates facultative ponds and rock filters (either unaerated or, if ammonia removal is required, aerated) are a low-cost but high-performance treatment system for small rural communities.
- In tropical climates a similar system can be used if effluent disposal is to a surface water, although anaerobic ponds would generally be used ahead of the facultative

**Table 1** Pathogen reductions achieved by health-protection control measures

<table>
<thead>
<tr>
<th>Control measure</th>
<th>Pathogen reduction (log_{10} units)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater treatment</td>
<td>1–7</td>
<td>The required pathogen reduction to be achieved by treatment depends on the combination of other health-protection control measures selected.</td>
</tr>
<tr>
<td>Drip irrigation</td>
<td>2–4</td>
<td>2-log reduction for low-growing crops and 4-log reduction for high-growing crops.</td>
</tr>
<tr>
<td>Pathogen die-off</td>
<td>0.5–2 d^{-1}</td>
<td>Die-off after last irrigation (value depends on climate, crop type, etc.).</td>
</tr>
<tr>
<td>Produce washing with water</td>
<td>1</td>
<td>Washing salad crops, vegetables and fruit with clean water.</td>
</tr>
<tr>
<td>Produce disinfection and rinsing with water</td>
<td>2</td>
<td>Washing salad crops, vegetables and fruit with a weak disinfectant solution and rinsing with clean water.</td>
</tr>
<tr>
<td>Produce peeling</td>
<td>2</td>
<td>Fruits, root crops.</td>
</tr>
</tbody>
</table>

*WHO (2006)*

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ponds, and a constructed wetland may often more appropriate than an aerated rock filter for nitrogen removal.

- If the treated wastewater is to be used for crop irrigation in tropical (or other warm) climates, then a 3-log unit pathogen reduction by treatment in a series comprising an anaerobic, a facultative and a single maturation pond is required for both restricted and unrestricted irrigation, provided that, in the case of unrestricted irrigation, there are in place post-treatment health-protection control measures that together provide a further 4-log unit pathogen reduction.

References


