The CIWEM World of Difference Award 2007

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on behalf of the
'Esholt Research Group'
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High-performance Low-cost Natural Wastewater Treatment Systems for Small Villages in the United Kingdom & Europe

INTRODUCTION

The UK water industry is a major consumer of electrical energy: it used 437 kWh per Ml of wastewater treated in 1998/99 (Water UK, 2003) and this increased to 663 kWh per Ml in 2004/05 (Water UK, 2006). Natural wastewater treatment systems use little or no electrical energy, and the 'price paid' for this is their requirement for a greater area of land than energy-intensive systems such as activated sludge. This makes them most suitable for small rural communities up to several hundred p.e. where land costs are not high: 'bareland' (i.e., farmland without any buildings on it) costs around £8,000 ha^{-1} (80p m^{-2}) (RICS, 2006). Land is, of course, an appreciating asset, whereas money spent on electricity is money gone for ever.[1] Furthermore, land *is* available: in 2005 there were ~559,000 ha of 'set-aside' land (land which the farmers are paid not to farm) in the whole of the UK (Defra, 2006).[2]

Waste stabilization pond (WSP) systems, which can easily be designed to merge into the local landscape (Figure 1), have been used for over 50 years to treat domestic, industrial and municipal wastewaters. The oxygen for bacterial BOD removal is supplied mainly by the pond algae and the CO_2 for algal photosynthesis comes mainly from the pond bacteria (Figure 2). They work more efficiently, in the sense of requiring less land for the same performance, in hot climates than in temperate climates. Nevertheless they are widely used in the United States (>7000 systems), France (>2500 systems) and Germany (>3000 systems, including ~1,500 systems in Bavaria alone), and they are the commonest form of wastewater treatment in New Zealand. However, they are little used in the United Kingdom: Abis (*PhD Thesis*, 2002)[3] reported only ~40 systems, all privately owned (i.e., not owned by the UK water companies or authorities).[4]

Given this experience of WSP in Europe, especially in countries with a climate not too dissimilar to that in the UK, and given Mara's extensive WSP R&D in both hot-climate and temperate-climate countries,[5] it seemed appropriate to determine the performance of WSP systems in the UK. Our first work was an investigation into the performance of the Burwarton Estate WSP in mid-Shropshire (Mara *et al*., 1998) and this was followed by the

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1 Of course, the adoption of natural treatment systems of the type described herein will make little difference to the total energy use by the UK water industry as its major use of electricity is at large and medium-sized works where the land for natural systems is not available. *But every little helps*.

2 Equivalent to ~90 m^2 per person in the UK in 2005 (when the population was 60.2 millions − ONS, 2006).

3 'Esholt' and other references are given on pp. 8−10.

4 Presently Yorkshire Water has one WSP system at Scrayingham (see p. 5) and Scottish Water has an Aero-fac® system at Errol, by Dundee (see Horan *et al*., 2007).

5 Principally Kenya, India and Brazil, and France and Portugal. Publications on this aspect of Mara's work are available at www.personal.leeds.ac.uk/~cen6ddm/PubsIndex.html.

Figure 2. WSP aesthetics: the primary facultative pond at Tigh Mor Trossachs, Perthshire, serving a holiday home complex (top). The facultative pond is followed by two maturation ponds (bottom). The final effluent discharges into Loch Achray (beyond the second maturation pond).
Pond design by Iris Water and Design, Castleton, North Yorkshire.

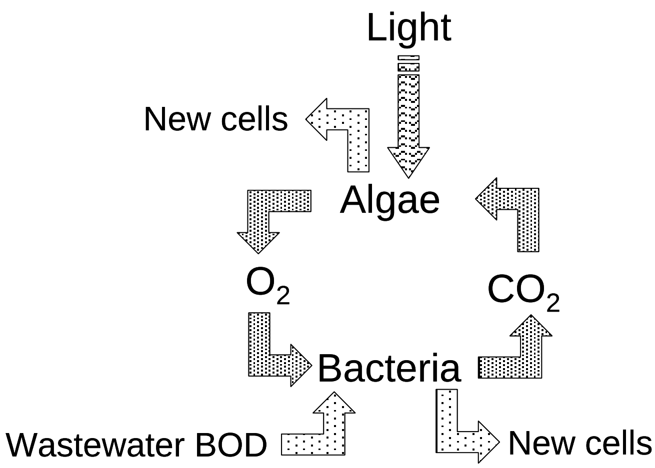

Figure 3. The mutualistic relationship between algae and bacteria in facultative and maturation ponds

work at pilot-scale at Yorkshire Water's wastewater treatment plant at Esholt, Bradford which was initiated by Mara and Abis in 1999.

The focus of this work at Esholt has been on assessing WSP performance in winter and summer in the UK, refining WSP design for UK and European conditions, and to develop a novel treatment system to 'polish' WSP effluents (in fact, facultative pond effluents) to minimize land area requirements and costs, while at the same time ensuring that the effluent complies with fairly strict discharge consents (e.g., BOD/SS/NH_4-N <10/15/5 mg l^{-1}).

Our work has now developed to the stage where its results have been used in practice for the design of a full-scale pond (as detailed on page 5) and where firm recommendations can be confidently made for the improved design of natural wastewater treatment systems for small communities of up to ~500 p.e., of which there are many in the European Union, including in the UK, currently without (or with inadequate) wastewater treatment (as described on pages 6−7).

WSP SYSTEMS RESEARCH AT ESHOLT

Primary facultative ponds

Abis (*PhD thesis*; *Esholt papers #2, 3, 5 & 6*) found that primary facultative ponds (Figure 3) performed very well at a BOD surface loading of 80 kg ha^{-1} day^{-1} (range investigated: 60−120 kg ha^{-1} day^{-1}). Unfiltered BOD and SS removals were both >80 percent, and filtered BOD removal (i.e., excluding the BOD due to the algae in the effluent) was always >95 percent. Ammonia-N removal was poor in winter (0−30%) but much better in summer (>50%). 'Electronic nose' measurements indicated zero odour in the vicinity of the ponds. Sludge accumulation (measured over 20 months) was low and the predicted desludging frequency 7−10 years.

Figure 3. Pilot-scale facultative ponds at Esholt (October 2005)

Abis' research has shown that a primary facultative pond receiving this BOD loading of 80 kg ha^{-1} day^{-1} is able to produce an effluent which complies with the requirements for WSP effluents in the Urban Waste Water Treatment Directive (Council of the European Communities, 1991) − i.e., ≤25 mg filtered BOD per litre and ≤150 mg SS per litre. This is an important finding for application in Member States whose environmental regulator does not specify a higher quality than this (e.g., Greece and several of the new accession countries).

The algal population was typical of those in facultative ponds in Europe, with *Chlorella*, *Chlamydomonas* and *Euglena* being the dominant genera. Although the algae grew extremely well in summer, they 'struggled' to survive in winter (temperatures <5°C and light intensities <50 W m^{-2}); there was some indication that this was partially due to the high non-algal SS levels in the ponds.

Baffles

Our recent work on the effect of baffles on facultative pond performance (*Esholt papers #18 & 19*) has confirmed that they do indeed improve performance. This work was started as 3D-CFD modelling of baffled ponds (only 2D-CFD models had been used before − Shilton and Harrison, 2003), and the work modelled for the first time the effects of wind velocity and thermal stratification. Work at pilot-scale on a primary facultative pond fitted with two, and then four, baffles equally spaced along the pond's longitudinal axis and with a length equal to 70% of the pond width, confirmed the CFD model results (Table 1).[6] We now consider that facultative ponds should always be baffled (with two, or better four, 70%-pond-width baffles equally spaced along the pond length), essentially as a matter of course.

Table 1. Faecal coliform numbers in effluents of ponds with and without baffles

System	Faecal coliform numbers per 100 ml			
	Isothermal conditions[a]		*Thermal stratification*[b]	
	Influent	Effluent	Influent	Effluent
Pilot-scale pond without baffles	5.4×10^6	3.0×10^5	1.5×10^7	3.6×10^5
Pilot-scale pond with 2 baffles	5.4×10^6	1.4×10^4	1.5×10^7	3.6×10^4
CFD model with 2 baffles	5.4×10^6	4.2×10^4	1.5×10^7	1.2×10^4

[a] Occurs mainly in winter. [b] Occurs mainly in summer.

Maturation ponds

Classically maturation ponds are considered an integral component of a WSP system: they remove ammonia-N and disinfect the wastewater. However, most of the ammonia is converted into algal organic N which leaves the pond with the algae, so that total N removal is low (*Esholt papers #7, 16 & 17*). Maturation ponds are fairly land-intensive: in France two maturation ponds are generally used and each requires 2.5 m^2 p.e.$^{-1}$ (Cemagref and Agences de l'Eau, 1997). Thus the ammonia-N and the algae in facultative pond effluents need to be removed and for this purpose we have developed aerated rock filters.

Aerated rock filters

Rock filters have been used to 'polish' maturation pond effluents in the United States for over 30 years (O'Brien *et al*., 1973; Swanson and Williamson, 1980; Middlebrooks, 1988, 1995; US EPA, 2002). In fact, rock filters should really be considered to be an integral part of a WSP system, just as secondary sedimentation tanks are considered an integral part of an activated sludge system, since they both serve the same purpose: the removal of biomass produced in the preceding biological treatment stage − bacteria in the case of activated sludge and algae in the case of WSP.

BOD and SS removals in rock filters are good and related to the hydraulic loading rate on the filters (HLR: m^3 of pond effluent per m^3 of rock filter volume per day − i.e., day^{-1}), but ammonia removal is essentially zero as the rock filters rapidly become anoxic. To permit ammonia removal by nitrification we developed an aerated rock filter to polish the effluent

[6] Work is still in progress on the pilot-scale pond with four baffles.

from a facultative (rather than a maturation) pond (*Esholt papers #8−12*); the HLR on the filter was 0.3 day^{-1} (equivalent, for a wastewater depth in the filter of 0.6 m, to 1 m^2 p.e.$^{-1}$ – much less than the 5m^2 p.e.$^{-1}$ for maturation ponds in France); the air flow into the 2 m^3 pilot-scale filter was 20 litres per minute. The aerated filter was compared at pilot-scale with an unaerated filter and a subsurface horizontal-flow constructed wetland (Figure 4). Aeration achieved good removal of ammonia-N (>50% *vs.* −150−50% in the unaerated filter), and also significantly improved BOD and SS removals (>75% and >80%, respectively, *vs*. 0−75% and 25−80% in the unaerated filter). The aerated rock filter outperformed both the subsurface horizontal-flow constructed wetland and the unaerated control, and also maturation ponds, in terms of BOD, SS and ammonia-N removals in both winter and summer (*Esholt papers #13, 18 & 22*). Mean effluent quality (mg/l) from the aerated rock filter in winter was 6/9/5 BOD/SS/NH_4-N in 2004/05 and 11/8/4 in 2005/06, which is very satisfactory.

Microbiological quality. Effluent faecal coliform numbers were <1000 per 100 ml throughout the year and <100 per 100 ml in summer, thus making the aerated rock filter effluent suitable for agricultural (or, in likely UK application, more probably horticultural) reuse (WHO, 2006).

Figure 4. Pilot-scale subsurface horizontal-flow constructed wetland (planted with Typha*) and aerated and unaerated rock filters treating facultative pond effluent at a hydraulic loading rate of 0.3 d^{-1} at Esholt, Bradford, UK. Each filter measures 4 × 0.5 × 0.5 m. Left, summer; right, winter.*

APPLICATION OF ESHOLT RESEARCH

The most significant application of our research to date has been the design of the facultative pond at Yorkshire Water’s ‘Ecological Wastewater Treatment Plant’ at Scrayingham, North Yorkshire (Figures 5 & 6). The designer, Andrew Joiner of Iris Water & Design (Castleton, N. Yorks), specifically used a BOD loading of 80 kg ha^{-1} day^{-1} to design the pond, based on Abis’ finding that this was the optimal loading in the UK winter (Abis, *PhD Thesis*).

The Scrayingham WSP system has won three major awards for Yorkshire Water: the Yorkshire ICE Prize 2005, the BCIA Environment Award 2005, and the CIWEM/RSPB Living Wetlands Award 2006. Recent work by a final year student at Leeds (Long, *MEng Dissertation*, 2006) found that the Scrayingham pond system works well and meets its consent.

Figure 5. The primary facultative pond at Scrayingham, North Yorkshire

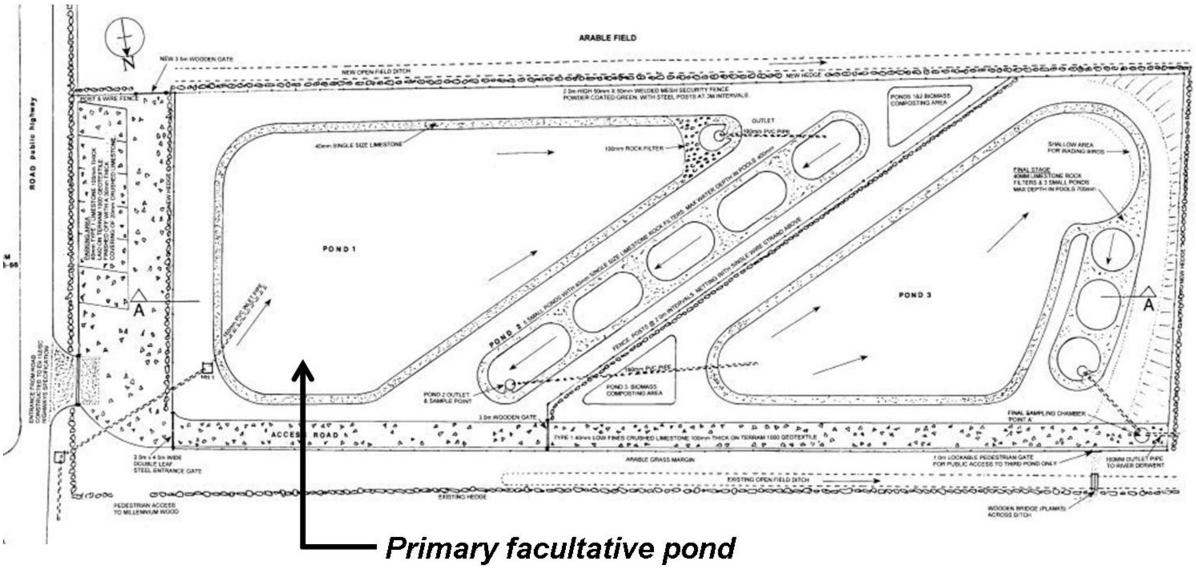

Figure 6. Layout of the WSP system at Scrayingham, North Yorkshire

FUTURE APPLICATIONS OF THE ESHOLT RESEARCH

Our research has enabled us to make a coherent set of recommendations for small natural wastewater treatment systems to serve communities of up to ~500 p.e. (*Esholt paper #15*), based on a wastewater flow of 200 litres p.e.$^{-1}$ day^{-1} (British Water, 2005) and a BOD contribution of 50 g p.e.$^{-1}$ day^{-1}.[7] The treatment train for 500 p.e. is as follows:

> (1) two septic tanks in series, the first of 72,000 litres and the second of 36,000 litres [i.e., effectively a two-compartment septic tank with the first compartment twice the size of the second) − this arrangement can serve 530 p.e. according to BS6297:1983 (BSI, 1983];[8]

[7] Despite the definition in the UWWTD of 1 p.e. as 60 g BOD p.e.$^{-1}$ day^{-1}, 50 g p.e.$^{-1}$ day^{-1} is conservative in rural areas: Pujol and Liénard (1990) measured 35−40 g p.e.$^{-1}$ day^{-1} in rural France.
[8] These prefabricated septic tanks are available from Titan Pollution Control, Andover (www.titanpc.co.uk).

(2) a secondary facultative pond loaded at 80 kg BOD ha^{-1} day^{-1} − assuming 40% BOD removal in the septic tanks, the pond area is 3.75 m^2 $p.e.^{-1}$ (this compares with 5 m^2 $p.e.^{-1}$ for a secondary subsurface horizontal-flow constructed wetland − Cooper, 2001); and

(3) an aerated rock filter − area requirement of 1 m^2 $p.e.^{-1}$ for an HLR of 0.3 day^{-1} and a wastewater depth of 0.6 m.

The overall site area for such a plant for 500 p.e. is ~6 m^2 $p.e.^{-1}$ and the estimated cost ~£375 $p.e.^{-1}$ (*Esholt paper #15*).

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COMPLIANCE WITH ENTRY CRITERIA

►*Relation to water cycle:*

Integral component of the domestic water cycle − as is the case for all wastewater treatment systems.

►*Application stage & specificity:*

The natural wastewater treatment system is ready for practical application now, specifically in rural areas for small villages of up to ~500 p.e. One part of the system, the facultative pond, has already been applied by Yorkshire Water at Scrayingham.

►*Innovation and achievability:*

The research on which this submission is based is wholly innovative in the UK, with features (e.g., the development of aerated rock filters; rational comparison of WSP systems and constructed wetland systems) that are globally innovative. All components of the proposed system (described immediately above) are known to work at full-scale in the UK (septic tanks, facultative ponds) or have been rigorously investigated at pilot scale (and not ‘small’ pilot scale) (aerated rock filters), so achievability is very high.

►*Sustainability:*

Low-cost capital and O&M costs; simple O&M for which only unskilled labour is required; very low sludge production (and sludge removal required only every few years; no further sludge treatment needed).

►*Benefit to the Environment:*

Minimization of electrical energy use; contribution to local aesthetics; production of effluents suitable and safe for irrigation [effluents in conformity with the recommendations in the World Health Organization’s recently revised Guidelines for wastewater use in agriculture (WHO, 2006)].

MEMBERS OF THE ‘ESHOLT RESEARCH TEAM’

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‘ESHOLT’ PUBLICATIONS

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MSc(Eng) Research Thesis

R. E. Epworth, *Ammonia Volatilization Rates in Primary Facultative and Maturation Wastewater Ponds in the United Kingdom*. University of Leeds, 2004.

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