4

WASTE STABILIZATION PONDS

4.1 INTRODUCTION

Waste stabilization ponds (WSP) have not been as popular in the UK as constructed wetlands (Chapter 3). There are only ~50 systems and all but two are privately owned (the two exceptions are Yorkshire Water's WSP at Scrayingham in North Yorkshire and Scottish Water's Aero-fac®[1] lagoons at Errol, by Dundee). These privately owned WSP serve small populations (2−1000 people) in individual homes, holiday apartment complexes (Figure 4.1), rural 'self-sufficient' communities (for example, those operated by the Camphill Trust[2]), privately owned Estate villages, and a motorway service area (Abis, 2002). However, performance data have been only been reported for one full-scale UK WSP system (Mara *et al*., 1998); more data are available from the University of Leeds' pilot-scale WSP located at Yorkshire Water's wastewater treatment works at Esholt, Bradford; Mara *et al*., 2002). In contrast to the UK, there are close to 3000 WSP systems in France (Cemagref and Agences de l'Eau, 1997; Racault and Boutin, 2005). Bucksteeg (1987) reported ~1100 systems in Germany; this number has now grown to ~2500, including ~1500 in Bavaria alone (Schleypen, 2003).

An introduction to WSP for non-specialists is given by Peña Varón and Mara (2004). More detailed information is given in Mara and Pearson (1998), Mara (2004) and Shilton (2006), as well as in the issues of *Water Science and Technology* which contain the proceedings of the IWA international and regional conferences on WSP.[3]

---

[1] Aero-fac is a registered trademark of LAS International (Europe) Ltd, King's Lynn PE34 3ES.
[2] www.camphilll.org.uk
[3] Issues available on-line at www.iwaponline.com/wst/toc.htm: vol. 31, no. 12 (1995); vol. 33, no. 7 (1996); vol. 42, no.10−11 (2000); vol. 45, no. 1 (2002); vol. 48, no.2 (2003); and vol. 51, no. 12 (2005).

Figure 4.1. 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

Properly designed and constructed WSP systems are robust, simple to operate and maintain, produce excess sludge very infrequently, and do not smell. They require a greater land area than conventional electromechanical treatment plants, but this is not a serious disadvantage for small rural communities (this point is discussed further in Chapters 1 and 6).

WSP systems in the UK comprise a facultative pond and one or two maturation ponds. Anaerobic ponds are not used, doubtless because of a fear of odour release (but they are commonly used in southern Germany and odour release is not experienced).

4.2 FACULTATIVE PONDS

4.2.1 Description

Facultative ponds are either 'primary' facultative ponds, which receive untreated wastewater (i.e., after only preliminary treatment) (Figure 4.2), or 'secondary' facultative ponds, which receive the effluent from septic tanks[4] (or anaerobic ponds). In both cases the pond working depth is 1−2 m, with 1.5 m being most commonly used. Wastewater treatment is achieved by the mutualistic activities of bacteria and algae (Figure 4.2): the usual genera of heterotrophic bacteria found in biological wastewater treatment plants oxidize the BOD and, and this is the microbiological feature unique to facultative and maturation ponds, several genera of mainly green micro-algae (Figure 4.4 and Table 4.1) photosynthetically produce the oxygen needed by the bacteria; and the bacteria produce the CO_2 fixed into cell carbon by the algae as they photosynthesize.[5] The general equation for algal photosynthesis is (Oswald, 1988):

$$106CO_2 + 236H_2\mathbf{O} + 16NH_4^+ + HPO_4^{2-} \xrightarrow{\text{light}} C_{106}H_{181}O_{45}N_{16}P + 118\mathbf{O_2} + 171H_2O + 14H^+$$

This shows that oxygen is produced as a by-product from water and that 1 g of algae produces ~1.55 g of oxygen (sufficient to satisfy the oxygen demand of 1.55 g of ultimate BOD or ~1 g of BOD_5). The algae most commonly found in the fairly turbid waters of facultative ponds are motile genera as these can optimize their position in the water column in relation to environmental factors, particularly the incident light intensity. The algae also have an important role in removing faecal bacteria (see Maturation Ponds below).

The effluent from both primary and secondary facultative ponds (and also maturation ponds) contain high numbers of algae which contribute to effluent SS and BOD. The BOD in facultative pond effluents (also in maturation pond effluents) is thus expressed as either 'unfiltered BOD', which includes the BOD due to the algae, or 'filtered BOD' which excludes it (filtered BOD is measured in the filtrate from standard filtration procedures for measuring SS). Unfiltered BOD removal in facultative ponds in the UK is 70−90 percent, filtered BOD removal >95 percent, and SS removal >90 percent (Abis, 2002; Abis and Mara, 2003, 2004, 2005a).

The Urban Waste Water Treatment Directive (Council of the European Communities, 1991) requires WSP effluents to contain ≤25 mg filtered BOD/l and ≤150 mg SS/l. This recognises the difference between algal and non-algal BOD and SS. In the receiving watercourse the algae produce more O_2 during daylight hours than they consume by respiration at night, so they make a positive contribution to the DO balance in the receiving watercourse. Furthermore WSP algae are consumed by protozoa and rotifers in the stream.

---

[4] See the design examples in Section 4.8 which show the advantage, in terms of reduced land area requirements, of pretreatment in a septic tank.

[5] Some O_2 and some CO_2 enters the pond from the atmosphere, but most is produced by the pond algae and bacteria.

Figure 4.2. Primary facultative pond at Scrayingham, North Yorkshire

Pond design by Iris Water and Design, Castleton, North Yorkshire

The Scrayingham WSP won Yorkshire Water the 2005 ICE Yorkshire Award and the 2005 BCIA Environmental Award (Kitching, 2005; BCIA, 2005)

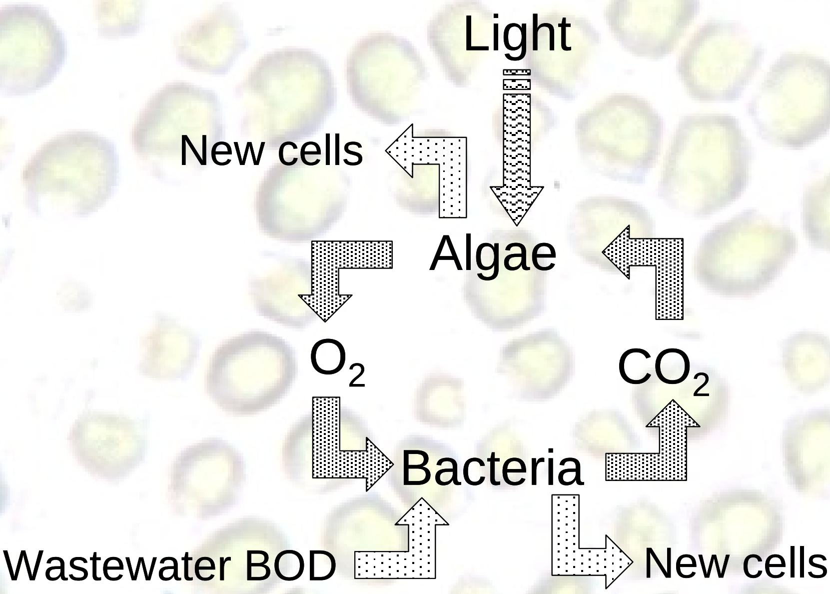

Figure 4.3. The mutualistic relationship between algae and bacteria in facultative and maturation ponds

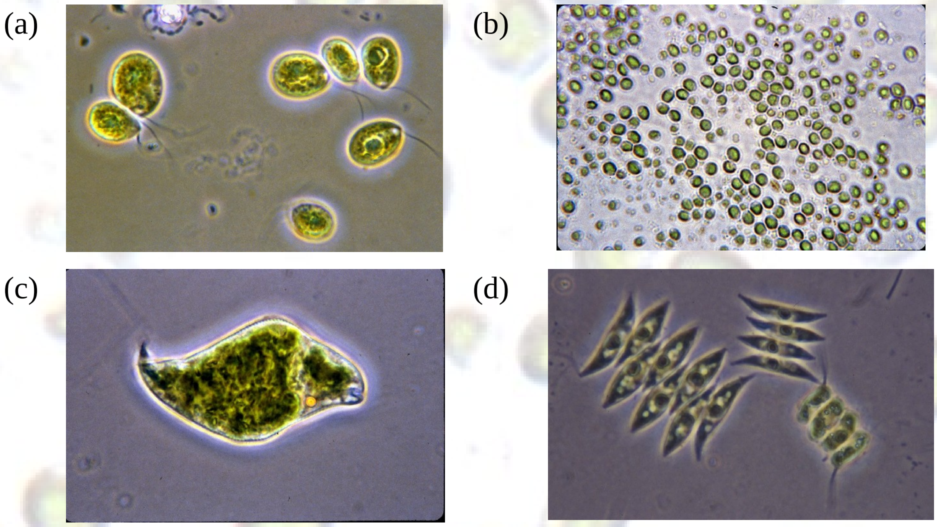

Figure 4.4. Algae typically found in facultative ponds: (a) *Chlamydomonas*; (b) *Chlorella*; (c) *Euglena*; (d) *Scenedesmus*

Photomicrographs courtesy of Professor Francisco Torrella, University of Murcia

Table 4.1. Algal species commonly found in facultative and maturation ponds

Alga	Facultative ponds	Maturation ponds
Euglenophyta		
_Euglena_*, [E]	+	+
_Phacus_*, [E]	+	+
Chlorophyta		
_Chlamydomonas_*, [E]	+	+
_Chlorogonium_*	+	+
Eudorina	+	+
_Pandorina_*	+	+
_Pyrobotrys_*	+	+
Ankistrodesmus	−	+
Chlorella[E]	+	+
Micratinium	−	+
Scenedesmus[E]	−	+
Selenastrum	−	+
_Carteria_*	+	+
Coelastrum	−	+
Dictyosphaerium	−	+
Oocystis	−	+
_Volvox_*	+	−

*, motile; [E], found by Abis (2002) in primary facultative ponds at Esholt, Bradford; +, present; −, absent.

4.2.2 Process design

Facultative ponds are designed on the basis of a permissible BOD surface loading (λ_S, expressed in units of kg BOD per hectare per day):

$$\lambda_S = \frac{10 L_i Q}{A_F} \tag{4.1}$$

where L_i is the influent BOD (mg/l); Q the inflow (m^3/d); and A_F the facultative pond area (m^2).

The permissible loading varies with mean monthly temperatures (T, °C) as follows (Mara, 1987):

$$\lambda_S = 350(1.107 - 0.002T)^{T-25} \tag{4.2}$$

subject to λ_S = 80 kg/ha d at temperatures ≤8°C. Since winter temperatures in the UK are <8°C, the design loading adopted is 80 kg/ha d (Abis, 2002; Abis and Mara, 2003, 2004). This design loading is used in New Zealand (Ministry of Works and Development, 1974) and is close to the value used in France (83 kg/ha d; Cemagref and Agences de l'Eau, 1997).

Thus, for this design loading, the facultative pond area is given by:

$$A_F = \frac{L_i Q}{8} \tag{4.3}$$

In fact this area is the mid-depth area of the pond, from which the surface and base areas and hence dimensions (using a length-to breadth ratio of 2−3 to 1) are determined, as shown in Figure 4.5.

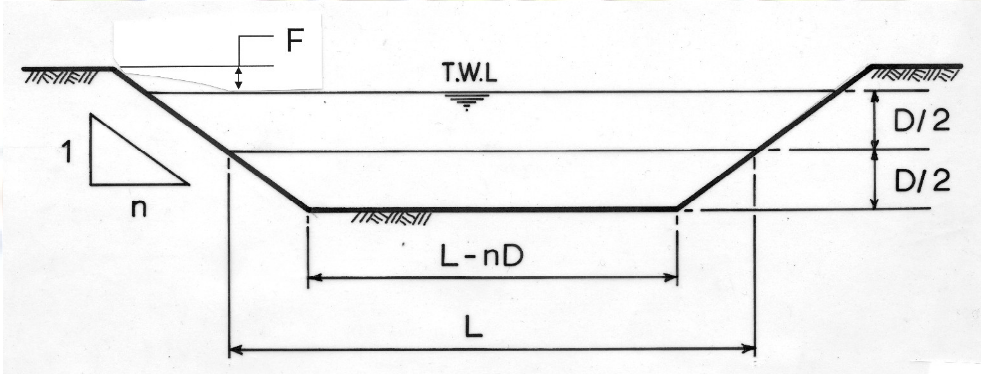

Figure 4.5. Determination of base dimensions of a pond from its mid-depth dimensions (shown here for its mid-depth length, L). F is the freeboard (at least 0.5 m to prevent wind-induced waves overtopping the embankment).

4.2.2.1 Retention time

The mean hydraulic retention time (θ_F, days) is volume/flow. For facultative ponds the flow is the mean of the inflow and outflow:

$$\theta_F = \frac{A_F D_F}{0.5(Q_i + Q_e)} \tag{4.4}$$

where D_F is the facultative pond depth (1.5 m); and Q_i and Q_e are the inflow and outflow, respectively (m^3/d).

The outflow is the inflow less losses due to evaporation and seepage. Assuming seepage is negligible (see Section 4.5), then:

$$Q_e = Q_i - 0.001 e A_F \tag{4.5}$$

where e is the net evaporation (i.e., evaporation − rainfall) (mm/d). Thus:

$$\theta_F = \frac{2 A_F D_F}{2Q_i - 0.001 e A_F} \tag{4.6}$$

4.2.2.2 Effluent BOD

The unfiltered BOD in the facultative pond effluent (L_e, mg/l) is calculated from the first-order equation:

$$L_e = \frac{L_i}{1 + k_{1(T)}\theta_F} \tag{4.7}$$

where $k_{1(T)}$ is the value of the first-order rate constant for unfiltered BOD removal at T °C (day^{-1}), given by:

$$k_{1(T)} = 0.3(1.05)^{T-20} \tag{4.8}$$

This design value of k_1 at 20°C (0.3 day^{-1}) is for primary facultative ponds; for secondary ponds it is 0.1 day^{-1}.

The filtered BOD is ~$0.3L_e$. This assumes that 70 percent of the effluent BOD is due to the algae (in practice the range is 70−90 percent) (Abis, 2002; Abis and Mara, 2003).

Facultative ponds in the UK loaded at 80 kg BOD/ha d produce an effluent complying with the UWWTD requirements for WSP effluents (Abis, 2002; Abis and Mara, 2003). However, there is currently only one pond system in the UK (the Aero-fac® lagoon system at Errol, by Dundee; see Section 4.2.4) which has had the UWWTD pond effluent quality applied to it.

The design procedure is illustrated in the design example given in Section 4.8.

4.2.3 Odour

WSP that are not overloaded do not smell. Field observations in summer 2002 on two full-scale WSP systems in North Yorkshire and the pilot-scale WSP at Esholt, Bradford, using three human noses and an electronic nose (described in Figueiredo, 2002) found no odour (less, in fact, than at conventional wastewater treatment works). Early work in the United States found no odour from WSP when the sulphate concentration in the raw wastewater was <500 mg SO_4^{2-}/l (higher concentrations would lead to correspondingly higher in-pond sulphide concentrations with consequently greater risks of H_2S release) (Gloyna and Espino, 1969).[6]

4.2.4 Mixed facultative ponds

Abis (2002) found that the algae in primary facultative ponds 'struggled' to survive in winter at temperatures <5°C and light intensities of ~20 W/m^2. Gentle mixing (really, gentle stirring or circulation) of the ponds is beneficial, and this can be achieved by floating electric mixer/circulator pumps[7] or by wind-powered aerator/mixers.[8] Stirred ponds are usually 2−3 m deep (*vs* 1.5 m for unstirred ponds). Electric mixer/circulator pumps (Figure 4.6) are inexpensive: a 250-watt unit for a facultative pond serving a population of up to ~500 costs around USD 4600 (f.o.b.);[7] energy input is minimal: ~0.1 W/m^3 (vs ~5 W/m^3 in a completely mixed aerated lagoon, for example).

Wind-powered aerator/mixers are used at Scottish Water's Aero-fac® lagoon system at Errol, by Dundee (Figure 4.7). These lagoons are also provided with supplementary diffused aeration which switches on automatically when the dissolved oxygen concentration in the lagoon falls below 4 mg/l. The final effluent quality is much better than required: ~8 mg unfiltered BOD/l and ~6 mg filtered BOD/l (the consent is ≤30 mg filtered BOD/l) (LAS International, 2005; see also Salih, 2004 and Horan *et al*., 2005).[9] The cost of the Errol lagoons was £840 000 for a design population of 2000 (the whole scheme, including interceptor sewers, rising main, inlet works and effluent outfall to the River Tay, cost £1.6 million, or £800 per person, in 2001).

A good alternative for small facultative ponds (serving up to around ~100 people) is to pretreat the wastewater in a septic tank (Chapter 2; see also the design example in Section 4.8) and/or internally circulate the facultative pond contents by means of a pump and a cascade (e.g., a series of 'Flowforms'[10]) (Figure 4.8).

---

[6] The maximum permissible sulphate concentration in drinking water is 250 mg/l; sulphate concentrations in wastewater are higher than in drinking water as detergents contain up to 40 percent (w/w) $NaSO_4$.

[7] For example, the model Enviro 700 floating circulator pump manufactured by Sunset Solar Systems Ltd, Assiniboia, SK S0H 0B0, Canada (www.pondmill.com).

[8] For example, the Mark 3 wind-powered aerator/mixer manufactured by LAS International (Europe) Ltd, King's Lynn PE34 3ES (www.lasinternational.com).

[9] The population currently served is ~1200 (*vs* the design population of 2000).

[10] For example, www.flowforms.com. For a more philosophical (indeed 'anthroposophical') account see Moodie (1997).

Figure 4.6. Floating electric mixer/circulator pump on a facultative pond in Canada

Photograph courtesy of Solar Sunset Systems Ltd

Figure 4.7. The primary Aero-fac® lagoon at Errol, by Dundee, showing the wind-powered aerators

Photograph courtesy of Ms Michelle Johnson, School of Civil Engineering, University of Leeds

Figure 4.8. One of the four secondary facultative ponds at Hawkwood College, near Stroud (see also Figure 1.2). The pond contents are internally circulated by a 200-W submersible pump (housed at P) which pumps the contents at a rate of ~100 l/min to the top of the 'flowform' cascade (bottom left). This induces a gentle circular motion in the pond. (A similar cascade can be seen in the primary facultative pond shown in Figure 4.1.) Each of the four ponds has a different design of cascade, each of which induces a slightly different circulation pattern in the pond; this will permit the 'best' system, in terms of performance and biodiversity, to be established. Apart from treating wastewater, the idea of this WSP system was to produce a very aesthetic, tranquil locality for contemplation and meditation (a bench will be located on the small gravelled area shown in the top right corner).

Pond design by Ebb & Flow Ltd, Nailsworth, Gloucestershire.

4.3 MATURATION PONDS

4.3.1 Description

The principal function of maturation ponds is threefold: (a) to reduce the BOD and SS in the facultative pond effluent; (b) to remove faecal bacteria; and (c) to reduce the concentration of ammonia-nitrogen. The decision whether to have maturation ponds or rock filters (Chapter 5), or constructed wetlands (Chapter 2), should be taken carefully as maturation ponds have a large land area requirement (for example, in France a facultative pond designed with 6 m^2 per person is followed by two maturation ponds, each with an area of 2.5 m^2 per person; Cemagref and Agences de l'Eau, 1997).

4.3.2.1 Faecal bacterial removal

In facultative and maturation ponds the following mechanisms are mainly responsible for the die-off of faecal bacteria (Figure 4.9):

(a) high sunlight intensity increases the in-pond temperature and faecal bacteria die more quickly with increasing temperature;

(b) algal demand for CO_2 during periods of rapid photosynthesis (which generally occur in the late morning and early afternoon) is greater than its supply from the in-pond bacteria (Figure 4.2); as a result carbonate and bicarbonate ions dissociate to provide more CO_2:

$$2HCO_3^- \rightarrow CO_3^{2-} + H_2O + CO_2$$

$$CO_3^{2-} + H_2O \rightarrow 2OH^- + CO_2$$

The OH^- ions accumulate and can cause the in-pond pH to rise above 9.4, which is the critical threshold for faecal bacterial die-off (Parhad and Rao, 1974; Pearson *et al*., 1987); even in the UK in winter in-pond pH on a very sunny afternoon can rise to >10 in a primary maturation pond with faecal coliform numbers <1000 per 100 ml in the pond effluent.[11]

(c) The combination of high visible light intensity and high dissolved oxygen concentrations (>15 mg/l) leads to very rapid photo-oxidative death of faecal bacteria; this effect is enhanced at high in-pond pH values (Curtis *et al*., 1992).

4.3.2.2 Ammonia removal

In facultative and maturation ponds ammonia is removed mainly by the following mechanism:

algal uptake ⟶ sedimentation of organic nitrogen in dead algal cells ⟶ accumulation in pond sludge (with partial ammonification of the organic nitrogen and feedback to the bulk pond liquid phase).

Some ammonia may be lost by volatilization at high pH, but in fact the loss observed is very small (Epworth, 2004; Camargo Valero and Mara, 2005).

[11] Personal observation, Michelle Johnson (School of Civil Engineering, University of Leeds).

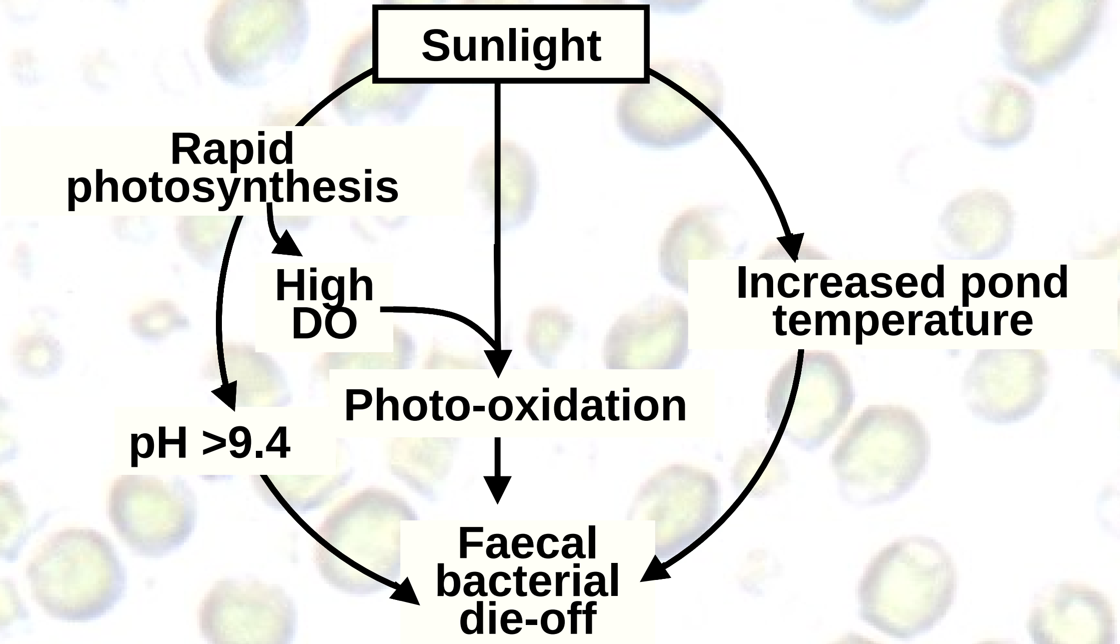

Figure 4.9. Principal mechanisms of faecal bacterial die-off in facultative and maturation ponds.

4.3.2 Process design

Maturation pond depths are usually 1−1.5 m (with a preference for 1 m). The first maturation pond is designed subject to three constraints:

(a) its retention time should not be greater than that of the preceding facultative pond,
(b) its retention time should not, in temperate climates, be less than 5 days, and
(c) the surface BOD loading on it should not be more than that on the facultative pond (and preferably no more than 70 percent of the facultative pond loading).

Considering constraint (c) first, and writing equation 4.1 for the first maturation pond, with $Q/A = D/\theta$ and $L_i = L_{e(Fac)}$ (as determined from equation 4.7):

$$\lambda_{S(M1)} = \frac{10 L_{e(Fac)} D_{M1}}{\theta_{M1}} \qquad (4.9)$$

where the subscript M1 refers to the first maturation pond. Rearranging and writing $\lambda_{S(M1)}$ as 0.7 $\lambda_{S(Fac)}$:

$$\theta_{M1} = \frac{10 L_{e(Fac)} D_{M1}}{0.7 \lambda_{S(Fac)}} \qquad (4.10)$$

The maturation ponds can now be designed either for faecal bacterial removal or ammonia-N removal (or both).

4.3.2.1 Faecal bacterial removal

The bacteria of interest are faecal (or thermotolerant) coliforms or (and preferably) *Escherichia coli*. The design equations of Marais (1974) are used, as follows:

$$N_e = \frac{N_i}{(1 + k_{B(T)}\theta_F)(1 + k_{B(T)}\theta_{M1})(1 + k_{B(T)}\theta_M)^n} \quad (4.11)$$

where N_e and N_i are the number of faecal bacteria per 100 ml of final effluent and untreated wastewater, respectively; $k_{B(T)}$ the first-order rate constant for faecal bacterial removal (day^{-1}); θ_M the retention time in each maturation pond subsequent to the first maturation pond (days); n the number of maturation ponds subsequent to the first (which, at this stage of the design, are assumed to be of the same size and shape). The value of $k_{B(T)}$ is strongly temperature-dependent:

$$k_{B(T)} = 2.6(1.19)^{T-20} \quad (4.12)$$

Equation 4.12 was derived from field data in the temperature range 2−21°C.

Equation 4.11 is rearranged as follows:

$$\theta_M = \frac{\left(\dfrac{N_i}{N_e(1 + k_{B(T)}\theta_F)(1 + k_{B(T)}\theta_{M1})}\right)^{1/n} - 1}{k_{B(T)}} \quad (4.13)$$

This equation is then solved for $n = 1$, then for $n = 2$, and so on, until the calculated value of θ_M is less than 5 days (the minimum permissible retention time to avoid massive hydraulic short-circuiting and algal wash-out). The designer then selects the most appropriate combination of n and θ_M (usually the one requiring least land). The procedure is illustrated in the design example given in Section 4.8.

The area of each maturation pond (including the first) is determined as follows:

$$A_M = \frac{2Q_i}{2D_M + 0.001e\theta_M} \quad (4.14)$$

where Q_i is the inflow (i.e., the outflow from the previous pond, determined from equation 4.5). The outflow from the pond whose area is being calculated is then determined; it is used as the inflow to the next maturation pond.

4.3.2.2 Ammonia removal

The equation of Pano and Middlebrooks (1982) for temperatures below 20°C (developed in the United States, but found to give reasonable results for ponds in the UK − Abis, 2002) is used:

$$C_e = \frac{C_i}{1 + (A/Q)(0.0038 + 0.000134T)e^{(1.041 + 0.044T)(pH - 6.6)}} \quad (4.15)$$

where C_e and C_i are the effluent and influent ammonia concentrations (mg N/l), respectively; and e is the base of Naperian logarithms. The equation is applied first to the facultative pond, and then in turn to each maturation pond, in order to determine the ammonia concentration in the final effluent.

4.4 POLISHING PONDS

Polishing ponds are short-retention-time ponds occasionally used as a final treatment stage at conventional treatment works. Their main function is to ‘smooth out’ fluctuations in effluent BOD and SS so that the effluent complies with its consent requirements. Their retention time is ~1 day (longer retention times would encourage algal growth, especially in summer, with a consequent increase in effluent BOD and SS). Most polishing ponds are not akin to maturation ponds (which, as described above, have entirely different functions), although some have been used specifically for bacterial removal (Toms *et al*., 1975). When designed for faecal bacterial removal, the following version of equation 4.13 should be used:

$$\theta_P = \frac{(N_i / N_e)^{1/n} - 1}{k_{B(T)}} \qquad (4.16)$$

where θ_P is the retention time in each of n polishing ponds (days); and N_i and N_e are the *E. coli* numbers per 100 ml of the influent to the first polishing pond and the effluent from the last, respectively.

4.5 PHYSICAL DESIGN

The physical design of WSP is at least as important as process design: a study of malfunctioning WSP in France found that half were malfunctioning because of problems (mainly geotechnical problems) which were not adequately addressed during the design stage (Drakides and Trotouin, 1991).

Particular attention should be paid to the WSP location. The site should be at least 200 m from the nearest houses, and it should slope gently to allow inter-pond flow by gravity. The soil should have an in-situ coefficient of permeability of $<10^{-7}$ m/s, otherwise the ponds should be lined. Embankment slopes are commonly 1 in 3 internally and 1 in 2−2.5 externally;[12] the embankments are planted with grass to minimize erosion. The length-to-breadth ratio of primary facultative ponds is typically 2−3 to 1; for secondary facultative and maturation ponds it can be much higher (up to 10 to 1). Liquid depths are generally 1.5 m in facultative ponds and 1 m in maturation ponds. In order to prevent embankment erosion by wind-induced waves, the embankment should be protected with precast concrete paving slabs set at top water level (stone rip-rap and lean in-situ concrete may also be used).

Conventional preliminary treatment (screening and grit removal) is not normally required at small WSP installations. In France a coarse (50-mm) screen is often used to remove

[12] Small ponds are often simply excavated and, where necessary, protected against storm run-off by French drains.

large objects (Drakides and Trotouin, 1991). If necessary, simple grit removal channels can be used (Marais and van Haandel, 1996). Figure 4.10 shows an inlet dosing chamber which also serves as a flow recorder.

Simple inlets and outlets should be located in diagonally opposite corners of the pond. A scum baffle around the inlet reduces material floating on the pond surface (Figure 4.11). Inlet pipes should discharge close to the side of the pond and below the pond surface to minimize floating materials. Outlet pipes should be protected by a scum guard to prevent blockage due to floating material which might enter the pipe.

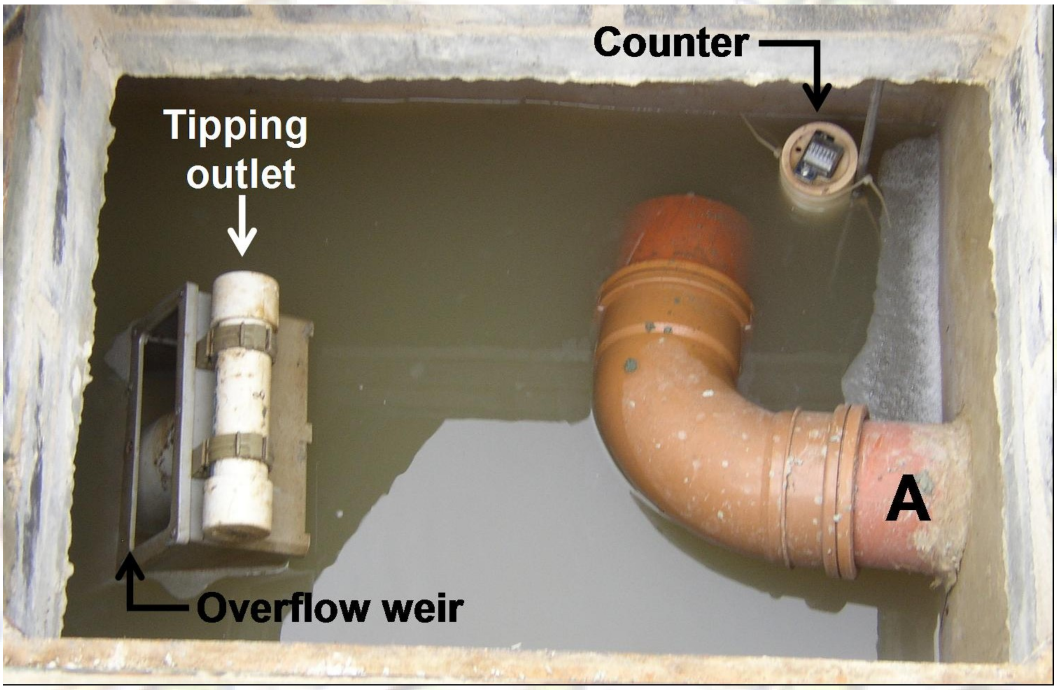

Figure 4.10. Dosing chamber feeding septic tank effluent to the secondary facultative ponds at Hawkwood College, near Stroud. A, inlet from septic tank. When the wastewater rises to the level of the effluent weir, it overflows into the outlet which then quickly tips over and the chamber contents are discharged into the receiving pond. The counter has an electrode set at the height of the overflow weir, so enabling the daily (or weekly) flow to be determined [= (chamber volume, m^3) × (difference in counter readings over a 24-hour (or 7-day) period)].

Chamber design by Mark Moodie (formerly of Elemental Solutions, Orcop, Hereford)

Figure 4.11. Scum baffle at the inlet of a primary facultative pond in France

Many WSP in the UK have been designed with marginal plants (Figures 1.2, 4.8 and 4.12). This improves site aesthetics and aquatic biodiversity, but it is not known if there is any resultant measurable effect on performance. There is, however, some evidence that marginal planting decreases the likelihood of duckweed infestation and blooms of *Daphnia.*

WSP hydraulics is an area now better understood (Shilton and Harrison, 2003a,b). As well as retaining scum and other floating material, the inlet scum baffle shown in Figure 4.11, provided it extends well down into the pond (preferably to ~1.2 m), reduces the momentum of the influent and so minimizes hydraulic short-circuiting.

Full details of WSP physical design are given by Environment Protection Agency (2004) and in Mara and Pearson (1998).

4.6 SAMPLING AND PERFORMANCE EVALUATION

A low-cost protocol for sampling WSP effluents and for the minimum evaluation of pond performance is given by Pearson et al. (1986); this publication should be consulted for further details.

Figure 4.12. Primary facultative pond at Botton Village, near Castleton, North Yorkshire, showing marginal planting.

Pond design by Iris Water and Design, Castleton, North Yorkshire.

4.7 OPERATION AND MAINTENANCE

WSP O&M is very simple and comprises the following routine tasks:

(a) removal of screenings and grit from the inlet works;
(b) cutting the grass on the embankments and removing it so that it does not fall into the pond;
(c) removal of floating scum and floating macrophytes, (e.g., duckweed) from the surface of facultative and maturation ponds (this is required to maximize photosynthesis and surface re-aeration and prevent fly and mosquito breeding);
(d) removal of any accumulated solids in the inlets and outlets;
(e) repair of any damage to the embankments caused by rodents, rabbits or other animals; and
(f) repair of any damage to external fences and gates.

Routine O&M in France is done by a two-person mobile crew which visits each WSP system for half a day every fortnight (Cemagref and Agences de l’Eau, 1997). This is feasible as there are several WSP systems in any one area. In the UK routine O&M of the privately owned WSP systems is done only occasionally (perhaps once every 4−8 weeks).

Mosquito breeding in WSP is not usually a problem, provided the ponds are properly operated and maintained. Abis (2002) found mosquito breeding in primary facultative ponds loaded at 60 kg BOD/ha d, but not in ponds loaded at ≥80 kg BOD/ha d. Stringham (2002) gives advice on mosquito control in WSP, including recommendations for suitable mosquito larvicide selection and application.

Sludge accumulates in primary facultative ponds at a rate of 0.08−0.16 m^3 per person per year (Abis and Mara, 2005b). In France the average rate is 0.11 m^3 per person per year (Racault and Boutin, 2005). Sludge removal is required after ~10 years when the pond is up to one-third full of sludge. Proprietary sludge removal systems (e.g., pontoon-mounted sludge pumps) are available.[13]

4.8 WSP DESIGN EXAMPLE

A WSP system is to be designed for a village with a population of 250. Design parameter values are:

Flow = 200 litres per person per day
BOD = 50 grams per person per day
Ammonia concentration = 30 mg N per litre
Design temperature (winter) = 5°C

- What is the effluent BOD from the facultative pond?

- How many maturation ponds are required to produce an effluent with 10 mg ammonia-N/l?

- How many maturation ponds would be required in summer (15°C) to reduce the *E. coli* count from 5 × 10^7 per 100 ml to ≤10^5 per 100 ml? (This would allow the effluent to be used for restricted irrigation − i.e., for the irrigation of all crops except those eaten uncooked; see WHO, 2006).

4.8.1 Solutions

4.8.1.1 Primary facultative pond
The flow is 50 m^3/day and the BOD concentration is 250 mg/l.
Design temperature is <8°C, so the design BOD loading is 80 kg/ha day. Thus, from equation 4.1:

$$10 L_i Q \quad 10 \times 250 \times 50$$

[13] Brain Associates, Carmarthen SA33 6JB.

From equation 4.6 with e = 0 (i.e., negligible evaporation in winter) and with D_{F} = 1.5 m:

$$\theta_F = \frac{A_F D_F}{Q} = \frac{1563 \times 1.5}{50} = 47 \text{ days}$$

At 5°C the value of $k_{1(T)}$ is given by equation 4.8 as:

$$k_{1(T)} = 0.3(1.05)^{5-20} = 0.14 \text{ day}^{-1}$$

The unfiltered effluent BOD is given by equation 4.7 as:

$$L_e = \frac{L_i}{1 + k_{1(T)}\theta_F} = \frac{250}{1 + (0.14 \times 47)} = 33 \text{ mg/l}$$

Therefore the unfiltered effluent BOD is ~0.3 × 33 ≈ 10 mg/l.

4.8.1.2 Maturation ponds − ammonia removal

A series of maturation ponds is designed for ammonia removal. First the ammonia-N concentration in the facultative pond effluent is calculated from equation 4.15 with an assumed pH value of 7.5:

$$C_e = \frac{C_i}{1 + (A/Q)(0.0038 + 0.000134T)e^{(1.041 + 0.044T)(\text{pH} - 6.6)}}$$

$$= \frac{30}{1 + (1563/50)(0.0038 + 0.000134 \times 5)e^{(1.041 + 0.044 \times 5)(7.5 - 6.6)}}$$

$$= 21 \text{ mg N/l}$$

The retention time in the first maturation pond (depth = 1 m) is given by equation 4.10:

$$\theta_{M1} = \frac{10 L_{e(Fac)} D_{M1}}{0.7 \lambda_{S(Fac)}} = \frac{10 \times 33 \times 1}{0.7 \times 80} = 6 \text{ days}$$

Its area is:

$$A_{M1} = \frac{Q\theta_{M1}}{D_{M1}} = \frac{50 \times 6}{1} = 300 \text{ m}^2$$

The ammonia-N concentration in the first maturation pond effluent is calculated with an assumed pH value of 7.5:

$$C_e = \frac{21}{1 + (300/50)(0.0038 + 0.000134 \times 5)e^{(1.041 + 0.044 \times 5)(7.5 - 6.6)}}$$

$$= 19 \text{ mg N/l}$$

This is a removal of ~10 percent. Thus a total of eight maturation ponds, each with a retention time of 6 days, would be required to produce an effluent with ~9 mg ammonia-N/l.

4.8.1.3 Maturation ponds − E. coli *removal*
The value of the first-order rate constant for *E. coli* removal at 15°C is given by equation 4.12:

$$k_{B(T)} = 2.6(1.19)^{T-20} = 2.6(1.19)^{15-20} = 1.1 \text{ day}^{-1}$$

Equation 4.11 is used to determine first the number of *E coli* in the facultative pond effluent:

$$N_{e(Fac)} = \frac{N_i}{1 + k_{B(T)}\theta_F} = \frac{5 \times 10^7}{1 + (1.1 \times 47)} \approx 10^6 \text{ per 100 ml}$$

Try one maturation pond with the minimum retention time (calculated above) of 6 days:

$$N_{e(M1)} = \frac{10^6}{1 + (1.1 \times 6)} \approx 1.3 \times 10^5 \text{ per 100 ml}$$

which is not satisfactory. Increase the retention time to 10 days:

$$N_{e(M1)} = \frac{10^6}{1 + (1.1 \times 10)} \approx 8 \times 10^4 \text{ per 100 ml}$$

which is satisfactory.

4.8.2 Alternative solutions

4.8.2.1 Septic tank and secondary facultative pond
For a population of 250 equation 2.1 gives the septic tank volume as:

$$C = 200P + 2000 = (200 \times 250) + 2000 = 52\ 000 \text{ litres}$$

This capacity can be provided by two septic tanks in series, the first with 36 000 litres and the second with 18 000 litres. BOD removal can be estimated as 40 percent, so the tank effluent BOD is (0.6 × 250) = 150 mg/l.

The secondary facultative pond has an area of:

$$A_F = \frac{10 L_i Q}{\lambda_S} = \frac{10 \times 150 \times 50}{80} = 938 \text{ m}^2$$

This area is 40 percent less than that of the primary facultative pond calculated above (3.75 m^2 per person *vs* 6.25 m^2 per person).

From equation 4.6 with $e = 0$ (i.e., negligible evaporation in winter) and with $D_F = 1.5$ m:

$$\theta_F = \frac{A_F D_F}{Q} = \frac{938 \times 1.5}{50} = 28 \text{ days}$$

The value of $k_{1(T)}$ in secondary facultative ponds at 5°C is:

$$k_{1(T)} = 0.1(1.05)^{5-20} = 0.05 \text{ day}^{-1}$$

The unfiltered effluent BOD is:

$$L_e = \frac{L_i}{1 + k_{1(T)}\theta_F} = \frac{150}{1 + (0.05 \times 28)} = 63 \text{ mg/l}$$

The filtered effluent BOD is ~0.3 × 63 ≈ 19 mg/l.

4.8.2.2 Ammonia removal

The series of maturation ponds calculated above for ammonia removal is scarcely economical, but it simply reflects the very low rate of ammonia removal at 5°C. Alternative solutions would include (a) a primary facultative pond (or a septic tank and a secondary facultative pond) followed by a constructed wetland (Chapter 3), and (b) a primary facultative pond followed by an aerated rock filter (Chapter 5).

4.9 CASE STUDY: COMBINED CW–WSP SYSTEM AT VIDARÅSEN, NORWAY

This Case Study is taken from the paper *Exceeding tertiary standards with a pond/reed bed system in Norway* by Browne and Jenssen (2005).[14] It is included here as it is a high-performance NWT system serving a small rural community located further north than the whole of mainland UK, where the winters are very cold (−5 to −25°C) and the short summers warm (15−25°C); rainfall is 1035 mm per year. The system serves the Camphill community at Vidaråsen (59°N, 10°E), approximately 100 km south of Oslo.

The combined CW−WSP system, which was commissioned in 1998, serves 160 people and receives the effluents from a dairy, a food-processing workshop, a bakery and a laundry. The wastewater flow is ~30 m^3/day and the total p.e. is ~200. The overall area is 10 m^2 per p.e. and the retention time is ~75 days. The treatment train comprises (Figure 4.13):

(a) two primary sedimentation tanks in series (volume = 13 m^3),
(b) two vertical-flow CW in parallel (pump-fed alternately for 7 days; area = 200 m^2), in series with
(c) two gravity-fed VF-CW (area = 100 m^2),
(d) an ‘enhanced’ facultative pond (300 m^2) with internal circulation with a flowform cascade,
(e) two maturation ponds in series (600 m^2 and 250 m^2), the first with internal cascade circulation,
(f) a VF-CW (90 m^2),
(g) a third maturation pond (200 m^2), and
(h) two subsurface horizontal-flow CW in series (90 m^2 and 100 m^2).

[14] This publication should be consulted for full details. Only an outline is given here.

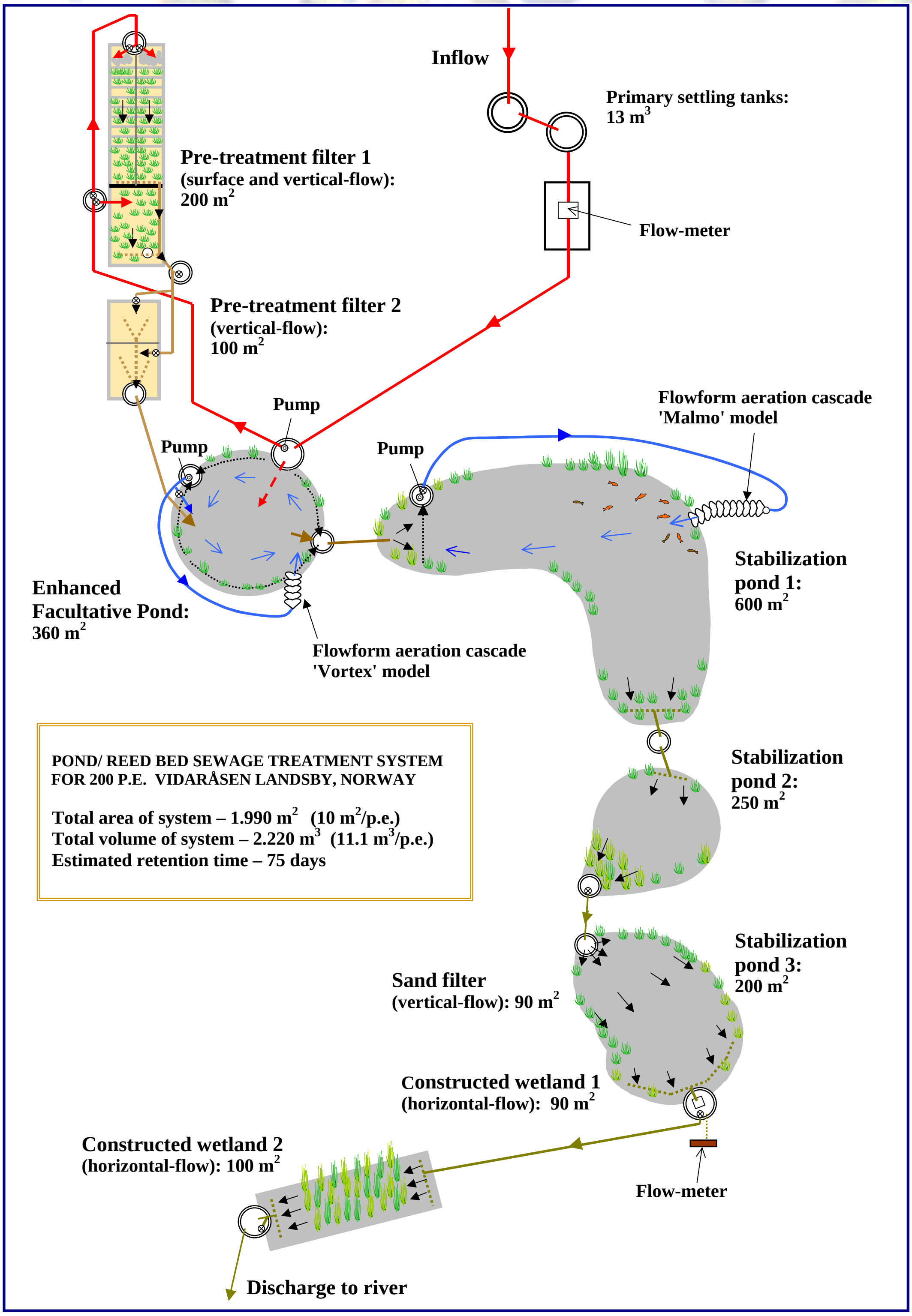

Figure 4.13. Combined CW−WSP treatment system at Vidaråsen, Norway

Source: Browne and Jenssen (2005)

The effluent is discharged to river. Effluent quality is very high, even in winter (Table 4.2): 96 percent P removal, 92 percent total N removal, 99.7 percent ammonia-N removal, 98 percent SS removal, and 94 percent removal of total organic carbon (TOC). The final effluent easily complies in both summer and winter with the discharge consent of ≤0.4 mg P/l. Effluent thermotolerant coliforms are <10 per 100 ml throughout the year.

Table 4.2. Influent and effluent concentrations (mg/l) for the various treatment stages in the combined CW−WSP treatment system at Vidaråsen, Norway

Parameter	Influent	VF-CW	Enhanced fac. pond	First mat. pond	Third mat. pond	SSHF-CW[a]
Total P	6.8	3.6	2.2	0.88	0.52	0.25
Total N	49	28	14	6.5	4.4	4.1
NH_4-N	46	11	3.2	0.33	0.24	0.13
TOC	85	19	8	6	5	5
SS	130	39	−	−	5	<3

[a] Final effluent.
Source: Browne and Jenssen (2005).