6

NWT TECHNOLOGY SELECTION

6.1 COMPARATIVE COSTS

6.1.1 Europe

Comparative costs of constructed wetlands and waste stabilization ponds in France in 1997 are given in Table 6.1, and in Germany in 1996 in Table 6.2. These tables show that WSP are cheaper than CW (and indeed other treatment processes) in both these countries. Pond desludging costs in France amount to ~€3.20 per person per year on average (range: €0.2−12) (Racault and Boutin, 2005).

In Greece Tsagarakis et al. (2003) found that WSP were the least-cost treatment process up to a land price of €28 000 per ha in 1999.[1]

Of course, the fact that WSP are cheaper than CW and other treatment technologies in these countries does not mean that this is necessarily also the case in the UK. However, these European cost data are a reasonable indicator that this might well be so. It is therefore always worth at least considering NWT technologies, especially WSP, for wastewater treatment in small villages in the UK. Added to this is the use of WSP by some small private communities in the UK: why would WSP have been chosen if they were unable to produce a compliant effluent at lower cost than other treatment technologies?

[1] Based on a case study in Sana'a, Yemen, Arthur (1983) similarly found that WSP were cheapest up to a land price of USD 50 000−150 000 per ha, depending on the discount rate used (5−15 percent).

Table 6.1. Capital and O&M costs of various wastewater treatment processes for a population of 1000 in France in 1997

Treatment process	Capital costs (ecu per person)[a]	O&M costs (ecu per person per year)[a]
Activated sludge	230	11.50
Trickling filter	180	7.00
RBC	220	7.00
Aerated lagoon	130	6.50
Vertical-flow CW[b]	*190*	*5.50*
WSP	*120*	*4.50*

[a] Average exchange rate in 1997: 1 ecu = £0.69 (www.oanda.com/convert/fxhistory).
[b] Two-stage VF-CW receiving raw wastewater.
Note: All processes designed to produce effluents complying with French regulations (see Alexandre *et al*., 1997; Racault and Boutin, 2005).
Source: Alexandre *et al*. (1997) (see also Berland and Cooper, 2001).

Table 6.2. Capital and O&M costs of various wastewater treatment processes for a population of 500 in Germany in 1996

Treatment process	Capital costs (DEM per person)[a]	O&M costs (DEM per m^3)[a]
Activated sludge	2,000	2.00
Trickling filter	1,500	1.70
Aerated lagoon	1,200	1.70
Horizontal-flow CW	*1,500*	*1.30*
Vertical-flow CW	*1,200*	*1.50*
WSP	*700*	*1.20*

[a]Average exchange rate in 1996: DEM 1 = £0.43 = 0.53 ecu (www.oanda.com/convert/fxhistory).
Source: Burka (1996).

6.1.2 United Kingdom

In the UK there are no direct comparative costs for CW and WSP, but there are individual costs for these two processes.

6.1.2.1 Constructed wetlands

Severn Trent Water has published its construction costs for subsurface horizontal-flow CW (Green and Upton, 1994, 1995): “the costs of tertiary [SSHF-CW] treatment systems [then 1 m^2 per person] have varied between about £100/head for 100 population to about £40/head for 1000 population. The secondary [SSHF-CW] treatment systems (for complete works) [i.e., primary treatment and 5 m^2 per person for the SSHF-CW] have varied from about £700 to £1600/head” (Green and Upton, 1995). These costs were confirmed by Upton *et al*. (1995), who also gave the costs of the RBCs preceding the tertiary SSHF-CW: ~£400−1000 per person for populations of 200−1000, and ~£500−2400 per person for populations <200. Thus the tertiary SSHF-CW accounted for only ~10−20 percent of the total cost. These 1994 costs can be converted to approximate first-quarter 2005 costs, and hence 2005 costs per m^2, using an index of 1.60 (Davis Langdon, 2006), as shown in Table 6.3.

Table 6.3. Conversion of SSHF-CW 1994 costs to 2005 costs

	1994 cost per p.e.	*2005 cost per p.e.*	*2005 cost per m^2*
Secondary SSHF-CW (5 m^2 per person)[a]	£700−1600	£1100−2600	£220−520
Tertiary SSHF-CW (1 m^2 per person)[b]	£40−100	£65−160	£65−160

[a]Cost includes primary treatment.
[b]Current sizing is 0.7 m^2 per p.e.

6.1.2.2 Waste stabilization ponds

The construction costs (excluding land costs) of the privately owned WSP system serving Burwarton Estate and village, near Bridgnorth, Shropshire, were £50 000 in 1994 (Mara et al., 1998). The total pond volume is 5000 m^3, so the construction cost was £10 per m^3 in 1994, equivalent to an approximate first-quarter 2005 cost of £16 per m^3 (using the same cost index as above for CW).

Land costs. The price of farmland (‘bareland’, i.e., without any buildings) in the UK is nearly £8000 per ha (i.e., 80p per m^2) (RICS, 2005). Thus land costs are a relatively small part of total costs − for example, for a primary facultative pond in the UK, they are ~6 percent (Table 6.4).

Table 6.4. Land and construction costs for a primary facultative pond in the UK

Area per person (m^2)	Cost of land (£ per person)[a]	Cost of construction (£ per person)[b]	Total cost (£ per person)
6.25	15	220	235

[a] Cost = (area per person, m^2) × 1.5 (to allow for embankments and access) × (£1.60 per m^2 − i.e., allowing for the land purchase price to be twice its market value).
[b] Cost = [(area per person, m^2) × (depth; taken as 2 m to include freeboard) × (£16 per m^3)] + 10%.

The land area requirement for a rock filter (A_{rf}) receiving a hydraulic loading rate (HLR) of 0.3 day^{-1} is given by:

$$A_{rf} = \frac{q}{(\mathrm{HLR}) \times D_{rf}} = \frac{0.2}{0.3 \times 0.6} = 1.1 \text{ m}^2 \text{ per person}$$

where D_{rf} is the wastewater depth in the RF (taken as 0.6 m).

The area of the RF is thus ~1.5 m^2 per person overall. Taking the 2005 RF cost as ~£100 per m^2 (i.e., the same as that for a tertiary SSHF-CW), the RF cost is ~£150 per person, so the overall cost of a primary facultative pond and a rock filter is of the order of £400 per person, which is very much less than the range given above for a secondary SSHF-CW system (including primary treatment).

6.2 TECHNOLOGY SELECTION

If the selection of an NWT treatment train is to be based as far as possible on rational grounds, then the selection criteria are land area, performance and cost.

6.2.1 Land area and performance

The land area requirements for CW and WSP systems are determined below for two levels of required effluent quality:

(a) ≤40 mg unfiltered BOD and ≤60 mg SS per litre (95-percentile values) (this is commonly required by the Environment Agency at small works in, for example, the Yorkshire Water area); and
(b) ≤15 mg unfiltered BOD, ≤25 mg SS per litre and ≤5 mg ammonia-N per litre (95-percentile values) (this is the strictest effluent quality in Table 3.1 set in the Severn Trent area).

The design parameters are taken as:

Wastewater flow: 200 litres per p.e. per day,
BOD: 50 g per p.e. per day,
Ammonia: 8 g N per p.e. per day, and
Winter temperature: <8°C

Thus the BOD is 250 mg/l and the ammonia concentration 40 mg N/l.

6.2.1.1 Constructed wetlands

The area (A_{cw}) of a secondary SSHF-CW is given by equation 3.6 as:

$$A_{cw} = \frac{Q_i\,(\ln L_i \;-\; \ln L_e)}{k_A}$$

where the design value of k_A is 0.06 m/d.

(a) ≤40 mg unfiltered BOD and ≤60 mg SS per litre (95-percentile values) ("40/60"): L_i is taken as 150 mg/l (i.e., 250 mg/l less 40 percent removed in, for example, a septic tank), and L_e as 20 mg/l as this is approximately equal to a 95-percentile value of 40 mg/l. Thus:

$$A_{cw} = \frac{0.2\,(\ln 150 \;-\; \ln 20)}{0.06} = 6.7 \text{ m}^2 \text{ per p.e.}$$

(b) ≤15 mg unfiltered BOD, ≤25 mg SS per litre and ≤5 mg ammonia-N per litre (95-percentile values) ("15/25/5"): the critical part of this effluent quality requirement is the 95-percentile ammonia concentration of ≤5 mg N/l. For a winter temperature of 7°C and assuming that partial ammonification of organic N in the septic tank increases the mean influent ammonia concentration (C_i) to 50 mg N/l, and that a 95-percentile ammonia concentration of 5 mg N/l is equivalent to a mean ammonia concentration of 1 mg N/l (Cooper, 2005b), A_{cw} is given by equations 3.5, 3.7 and 3.8 rewritten as follows:

$$\theta_{cw} = \frac{(\ln C_i - \ln C_e)}{0.126\,(1.008)^{T-20}} = \frac{(\ln 50 - \ln 1)}{0.126\,(1.008)^{7-20}} = 34 \text{ days}$$

$$A_{cw} = \frac{Q_i\,\theta_{cw}}{\varepsilon\,D_{cw}} = \frac{0.2 \times 34}{0.4 \times 0.6} = 28 \text{ m}^2 \text{ per p.e.}$$

This area is extremely large and in practice secondary SSHF-CW would not be used to achieve this degree of ammonia removal. (This also explains, at least in part, why Severn Trent Water's preferred strategy is to use a tertiary SSHF-CW to polish the effluent from a nitrifying RBC.)

6.2.1.2 Waste stabilization ponds

The design loading for facultative ponds in winter in the UK is 80 kg/ha day (= 8 g/m^2 day), so the area of a primary facultative pond is:

$$\frac{50\,\text{g per p.e. per day}}{8\,\text{g per m}^2\text{ per day}} = 6.25\ \text{m}^2\text{ per p.e.}$$

Assuming the BOD is reduced by 40 percent in, for example, a septic tank to 30 g per p.e. per day, the area of a secondary facultative pond is:

$$\frac{30\,\text{g per p.e. per day}}{8\,\text{g per m}^2\text{ per day}} = 3.75\ \text{m}^2\text{ per p.e.}$$

(a) 40/60 effluent quality: the facultative pond effluent has to be treated in a rock filter. As shown in Chapter 5, an unaerated rock filter receiving facultative pond effluent at an HLR of 0.3 day^{-1} produces a 95-percentile effluent BOD/SS of <40/60. As shown above, its area is 1.1 m^2 per p.e.

(b) 15/25/5 effluent quality: as shown in Chapter 5, an aerated rock filter receiving facultative pond effluent at an HLR of 0.3 day^{-1} produces a 95-percentile effluent BOD/SS/Amm.N of <10/15/5 mg/l. Its area is thus also 1.1 m^2 per p.e.

6.2.1.3 Area comparison

These land area requirements for CW and facultative ponds and rock filters are summarized in Table 6.5. It is apparent that, to achieve a 40/60 effluent quality, the secondary SSHF-CW requires 38 percent more land than the secondary facultative pond and unaerated rock filter. The CW is unable to achieve a 15/25/5 effluent quality as this quality has to be achieved in both summer and winter and it is unable to produce an effluent with a 95-percentile ammonia concentration ≤5 mg N/l in winter (unless it were

Table 6.5. Land area requirements for constructed wetland and waste stabilization pond systems designed to achieve two different effluent qualities

Wastewater treatment system	Land area requirements (m^2 per p.e) for:	
	40/60 effluent quality	15/25/5 effluent quality
Primary facultative pond and unaerated rock filter	7.35	n.a.[a]
Primary facultative pond and aerated rock filter	–[b]	7.35
Secondary facultative pond and unaerated rock filter	4.85	n.a.
Secondary facultative pond and aerated rock filter	–	4.85
Secondary subsurface horizontal-flow CW	6.7	28[c]

[a] Treatment system not able to produce this quality effluent.
[b] Treatment system would not be used to produce this quality effluent.
[c] In practice this treatment system would not be used to produce this quality effluent.

excessively large), whereas the secondary facultative pond followed by an aerated rock filter can.

6.2.2 Cost

Cost should be the lowest cost, although a treatment train with the lowest CAPEX may not necessarily have the lowest OPEX and it could be more expensive in net present value terms than one with a higher CAPEX but lower OPEX. However, this latter alternative may be financially more attractive as its higher OPEX is funded from revenue.

As shown above, the CAPEX of a secondary SSHF-CW (including the cost of the associated primary treatment) is at least 175 percent more expensive than a primary facultative pond and a rock filter.

6.2.3 Concluding remarks

Strict application of these land area, performance and cost criteria should therefore lead to the selection of either a primary facultative pond and a rock filter (aerated if required to remove ammonia), or a septic tank, a secondary facultative pond and a rock filter (aerated as necessary). Preference may be given to constructed wetlands for reasons of familiarity, apparent aesthetics or "politics",[2] but it should be at least recognised that this choice may not be always optimal.

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[2] Water companies using CW are often able to deflect criticism from 'green activists' simply by saying that they are using 'green technologies'. The same argument applies, of course, to WSP.