6

Process design of WSP

6.1 EFFLUENT QUALITY REQUIREMENTS

In member States of the European Union WSP effluents have to meet the same BOD and COD requirements as other effluents ($\ngtr$25 and $\ngtr$125 mg/l) but with one very important difference: *filtered* samples are used to determine the BOD and COD, which are therefore the residual non-algal values (Council of the European Communities, 1991*a*), although of course filtration removes non-algal solids as well – but in WSP effluents the algae comprise most (>80%) of the suspended solids. Furthermore in the EU pond effluents can contain up to 150 mg SS per litre, whereas effluents from other treatment processes can contain only 35 mg SS/l. This recognises the distinctions between algal and sewage BOD (and COD) and algal and sewage SS. The algae in WSP effluents readily disperse and are consumed by zooplankton in receiving waters, so they have little chance to exert their oxygen demand, and during daylight hours they of course *produce* oxygen. In agricultural reuse schemes pond algae are very beneficial: they act as slow-release fertilizers and increase the soil humus content and improve its water-holding capacity.

In the EU the quality requirements for WSP effluents being discharged into surface and coastal waters are thus:

Filtered BOD	≤ 25 mg/l
Filtered COD	≤ 125 mg/l
Suspended solids	≤ 150 mg/l

together with, for discharge into designated “sensitive areas subject to eutrophication”:

Total nitrogen	≤ 15 mg/l
Total phosphorus	≤ 2 mg/l

(although, if the population served is > 100,000, these last two requirements are reduced to ≤ 10 and ≤ 1 mg/l, respectively) (Council of the European Communities, 1991*a*).

Countries in the Region not within the European Union are urged to take into consideration the inherent difference between algal and sewage BOD (or COD) and SS, and so allow filtered BOD (and/or COD) to replace unfiltered BOD (and/or COD) in their requirements for WSP effluents, subject to a maximum permitted SS concentration (i.e. including the algae in the WSP effluent) of, for example, 150 mg/l (as in the EU), or some other locally appropriate value.

WSP effluents which are to be reused in agriculture or aquaculture should comply with:

(a) the WHO microbiological quality guidelines given in Table 12.1, and
(b) the FAO physicochemical quality guidelines given in Ayers and Westcot (1985) (see Section 12.2).

6.2 DESIGN PARAMETERS

The four most important parameters for WSP design are temperature, net evaporation, flow and BOD. Faecal coliform and helminth egg numbers are also important if the final effluent is to be used in agriculture or aquaculture.

6.2.1 Temperature and net evaporation

The usual design temperature is the mean air temperature in the coolest month (or quarter). This provides a small margin of safety as pond temperatures are 2-3 degC warmer than air temperatures in the cool season (the reverse is true in the hot season). Another design temperature commonly used is the air temperature in the coolest period of the irrigation season. Net evaporation (= evaporation – rainfall) has to be taken into account in the design of facultative and maturation ponds (Shaw, 1962), but not in that of anaerobic ponds, as these generally have a scum layer which effectively prevents significant evaporation. The net evaporation rates in the months used for selection of the design temperatures are used; additionally a hydraulic balance should be done for the hottest month (see Section 7.3).

6.2.2 Flow

The mean daily flow should be measured if the wastewater exists. If it does not, it must be estimated very carefully, since the size of the ponds, and hence their cost, is directly proportional to the flow. The wastewater flow should not be based on the design water consumption per caput, as this is unduly high since it contains an allowance for losses in the distribution system. A suitable design value is 85 percent of the in-house water consumption, and this can be readily determined from records of water meter readings. If these do not exist, the actual average 24-hour wastewater flow in the sewer can be measured; or alternatively the design flow may be based on local experience in sewered communities of similar socio-economic status and water use practice.

6.2.3 BOD

If the wastewater exists, its BOD may be measured using 24-hour flow-weighted composite samples (see Section 9.1). If it does not, it may be estimated from the following equation:

$$L_i = 1000\ B/q \qquad (6.1)$$

where L_i = wastewater BOD, mg/l
B = BOD contribution, g/caput d
q = wastewater flow, l/caput d

Values of B vary between 30 and 70 g per caput per day, with richer communities producing more BOD than poor communities (Campos and von

Sperling, 1996). The EU Directive on urban wastewater treatment (Council of the European Communities, 1991*a*) stipulates that one population-equivalent is to be calculated on the basis of 60 g BOD per caput per day, but outside of large urban centres this is likely to be an overestimate. In medium-sized towns a value of 50 g per caput per day is more suitable (Mara and Pearson, 1987), and in small villages a value of 40 g per caput per day may not be unreasonable.

6.2.4 Nitrogen

The general standards for various forms of nitrogen in effluent discharged into inland surface waters (Section 6.1) are not likely to cause difficulty, although more stringent requirements may need to be considered if the effluent is to be discharged into a pristine lake that would be subject to eutrophication.

Total nitrogen and free ammonia (NH_3, rather than $NH_4^+ + NH_3$) are important in the design of wastewater-fed fishponds (Section 12.4). Typical concentrations of total nitrogen in raw domestic wastewater are 20-70 mg N/l, and total ammonia ($NH_4^+ + NH_3$) concentrations are 15 – 40 mg N/l.

6.2.5 Faecal coliforms

Faecal coliform numbers are important if the pond effluent is to be used for unrestricted crop irrigation or for fishpond fertilization (Section 12). Grab samples of the wastewater may be used to measure the faecal coliform concentration if the wastewater exists. The usual range is 10^7-10^8 faecal coliforms per 100 ml, and a suitable design value is 5×10^7 per 100 ml.

6.2.6 Helminth eggs

Helminth egg numbers are also important when pond effluents are used for crop irrigation or fishpond fertilization (Section 12). If the wastewater exists, composite samples may be used to count the number of human intestinal nematodes eggs (see Ayres and Mara, 1996). The usual range is up to around 500 eggs per litre, with richer communities producing much fewer eggs than newly sewered poor communities (although egg numbers from the latter will fall over time as the opportunities for reinfection will be greatly reduced by the provision of sewerage).

6.3 ANAEROBIC PONDS

Anaerobic ponds can be satisfactorily designed – and without risk of odour nuisance (see Section 2.1.1 and below) – on the basis of volumetric BOD loading (λ_V, g/m^{3}d), which is given by:

$$\lambda_V = L_i Q / V_a \qquad (6.2)$$

where L_i = influent BOD, mg/l (= g/m^3)
Q = flow, m^3/d
V_a = anaerobic pond volume, m^3

The permissible design value of λ_V increases with temperature, but there are too few reliable data to permit the development of a suitable design equation. Mara and Pearson (1986) and Mara *et al.* (1998) recommend the design values given in Table 6.1 which may be safely used for design purposes in the Region. These recommendations were based on those of Meiring *et al.* (1968) that λ_V

should lie between 100 and 400 g/m^{3}d, the former in order to maintain anaerobic conditions and the latter to avoid odour release (see also Mara and Mills, 1994). However, in Table 6.1 the upper limit for design is set at 350 g/m^{3}d in order to provide an adequate margin of safety with respect to odour. This is appropriate for normal domestic or municipal wastewaters which contain less than 300 mg SO_4/l.

Once a value of λ_V has been selected, the anaerobic pond volume is then calculated from equation 6.2. The mean hydraulic retention time in the pond (θ_a, d) is determined from:

$$\theta_a = V_a/Q \qquad (6.3)$$

Retention times in anaerobic ponds <1 day should not be used. If equation 6.3 gives a value of θ_a <1 day, a value of 1 day should be used and the corresponding value of V_a recalculated.

The performance of anaerobic ponds increases significantly with temperature, and the design assumptions for BOD removal (needed for the design of the receiving facultative pond) given in Table 6.1 can be confidently adopted. These are based on experience with anaerobic ponds in Germany in winter (T < 10ºC) (Bucksteeg, 1987), and in northeast Brazil at 25ºC (Table 6.2) where conditions are very similar to those in the Eastern Mediterranean and North Africa in summer, for example.

Table 6.1 Design values of permissible volumetric BOD loadings on and percentage BOD removal in anaerobic ponds at various temperatures

Temperature (ºC)	Volumetric loading (g/m^{3}d)	BOD removal (%)
<10	100	40
10-20	20*T* -100	2*T* +20
20-25	10*T* + 100	2*T* + 20
>25	350	70

T = temperature, ºC.
Source: Mara and Pearson (1986) and Mara *et al.* (1997).

Table 6.2 Variation of BOD removal with retention time in anaerobic ponds in northeast Brazil at 25˚C[a]

Retention time (d)	Volumetric loading rate (g/m3/day)	BOD removal (%)
0.8	306	76
1.0	215	76
1.9	129	80
2.0	116	75
4.0	72	68
6.8	35	74

[a] The ponds were located in Campina Grande, Paraiba State (latitude 7º13'11"S, longtitude 35º52'31"W, altitude 550 m above m.s.l.). The mean BOD of the raw municipal wastewater was 230 – 290 mg/l.
Source: Silva (1982).

6.4 FACULTATIVE PONDS

Although there are several methods available for designing facultative ponds (Mara, 1976), it is recommended that they be designed on the basis of surface BOD loading (λ_S, kg/ha d), which is given by:

$$\lambda_S = 10\ L_i Q / A_f \qquad (6.4)$$

where A_f = facultative pond area, m^2

The permissible design value of λ_S increases with temperature (T, ºC). The earliest relationship between λ_S and T is that given by McGarry and Pescod (1970), but their value of λ_S is the *maximum* that can be applied to a facultative pond before it fails (that is, becomes anaerobic). Their relationship, which is therefore *an envelope of failure,* is:

$$\lambda_S = 60\ (1.099)^T \qquad (6.5)$$

A more appropriate global *design* equation was given by Mara (1987):

$$\lambda_S = 350\ (1.107\text{-}0.002T)^{T\text{-}25} \qquad (6.6)$$

Equations 6.5 and 6.6 are shown graphically in Figure 6.1, and Table 6.3 gives values of λ_S from equation 6.6 for the temperature range 8–25ºC.

The earlier design recommendations in France (ALTB/CTGREF, 1979) which were adopted for Mediterranean Europe (Mara and Pearson, 1987), that the loading on facultative ponds should be 100 kg/ha day at temperatures of 10ºC *and below*, have recently been revised following a review of WSP performance over 15 years in France (CEMAGREF *et al.*, 1997). The original French recommendation (ALTB/CTGREF, 1979) was for a facultative pond area of 5 m^2 per person. This was interpreted by Mara and Pearson (1987) as 100 kg/ha day on the basis of a daily BOD contribution of 50 g per person (50 g/person day ÷ 5 m^2 per person = 100 kg/ha day). Given that the mean temperature of the coldest month in France is < 10ºC, the original recommendations were for a winter loading on facultative ponds of 100 kg/ha day, i.e. at design temperatures of 10ºC *and below*.

Table 6.3 Values of the permissible surface BOD loading on facultative ponds at various temperatures (calculated from equation 6.6)

T (ºC)	λ_S (kg/ha d)	T (ºC)	λ_S (kg/ha d)
≤ 8	80	17	199
9	89	18	217
10	100	19	235
11	112	20	253
12	124	21	272
13	137	22	291
14	152	23	311
15	167	24	331
16	183	25	350

The recent review of WSP performance in France (CEMAGREF *et al.*, 1997) indicates that a more appropriate design basis for facultative ponds is 6 (rather than 5) m^2 per person. This is equivalent to a BOD loading of 83 kg/ha day,

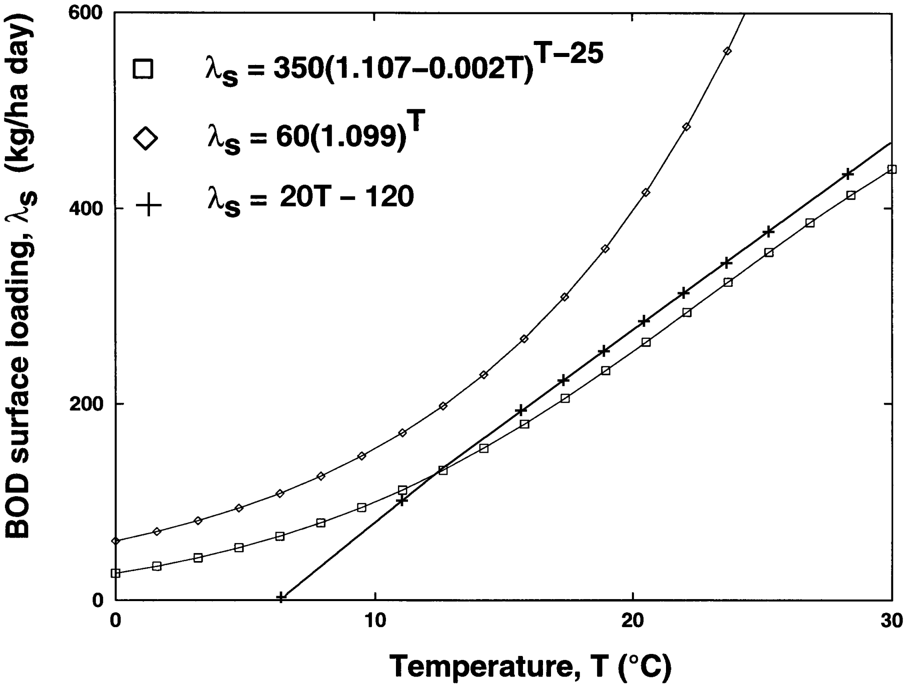

Figure 6.1 Variation of surface BOD loading on facultative ponds with temperature according to equations 6.5 and 6.6.

assuming a BOD contribution of 50 g/person day. This indicates that equation 6.6 may be used down to 8°C and that a design loading on facultative ponds of 80 kg/ha day should be used for design temperatures of 8°C *and below*. (Many parts of the Region have, of course, winter design temperatures higher than 8°C and this reduction in facultative pond loading from 100 to 80 kg/ha day is not applicable.)

Once a suitable value of λ_S has been selected, the pond area is calculated from equation 6.4 and its retention time (θ_f, d) from:

$$\theta_f = A_f D / Q_m \qquad (6.7)$$

where D = pond depth, m (usually 1.5 m – see Section 7.1)
Q_m = mean flow, m^3/day

The mean flow is the mean of the influent and effluent flows (Q_i and Q_e), the latter being the former less net evaporation and seepage. Thus equation 6.7 becomes:

$$\theta_f = A_f D / [{}^1/_2(Q_i + Q_e)] \qquad (6.8)$$

If seepage is negligible, Q_e is given by:

$$Q_e = Q_i - 0.001 e A_f \qquad (6.9)$$

where e = net evaporation rate, mm/day. Thus equation 6.8 becomes:

$$\theta_f = 2 A_f D / (2 Q_i - 0.001 e A_f) \qquad (6.10)$$

A minimum value of θ_f of 5 days should be adopted for temperatures below 20°C, and 4 days for temperatures above 20°C. This is to minimise hydraulic short-circuiting and to give the algae sufficient time to multiply (i.e. to prevent algal washout).

The BOD removal in primary facultative ponds is usually in the range 70-80 percent based on unfiltered samples (that is, including the BOD exerted by the algae), and usually above 90 percent based on filtered samples. In secondary facultative ponds the removal is less, but the combined performance of anaerobic and secondary facultative ponds generally approximates (or is slightly better than) that achieved by primary facultative ponds.

Design Example No. 1 in Annex I shows how anaerobic and facultative ponds are designed to produce an effluent suitable for surface water discharge.

6.5 MATURATION PONDS

6.5.1 Faecal coliform removal

The method of Marais (1974) is generally used to design a pond series for faecal coliform removal. This assumes that faecal coliform removal can be reasonably well represented by a first order kinetic model in a completely mixed reactor. The resulting equation for a single pond is thus:

$$N_e = N_i/(1 + k_T\theta) \quad (6.11)$$

where N_e = number of FC per 100 ml of effluent
N_i = number of FC per 100 ml of influent
k_T = first order rate constant for FC removal, d^{-1}
θ = retention time, d

For a series of anaerobic, facultative and maturation ponds, equation 6.11 becomes:

$$N_e = N_i/[(1+k_T\theta_a)(1+k_T\theta_f)(1+k_T\theta_m)^n] \quad (6.12)$$

where N_e and N_i now refer to the numbers of FC per 100 ml of the final effluent and raw wastewater respectively; the sub-scripts a, f and m refer to the anaerobic, facultative and maturation ponds; and n is the number of maturation ponds.

It is assumed in equation 6.12 that all the maturation ponds are equally sized: this is the most efficient configuration (Marais, 1974), but may not be topographically possible (in which case the last term of the denominator in equation 6.12 is replaced by $[(1+k_T\theta_{m1})(1+k_T\theta_{m2})...(1+k_T\theta_{mn})]$).

The value of k_T is highly temperature dependent. Marais (1974) found that:

$$k_T = 2.6\,(1.19)^{T-20} \quad (6.13)$$

Thus k_T changes by 19 percent for every change in temperature of 1 degC (see Table 6.4). Equation 6.12 contains the implicit assumption that the value of k_T determined from equation 6.13 is equally valid in anaerobic, facultative ponds. This is, of course, not true but Pearson *et al.* (1996*a*) nonetheless found that equation 6.12 represents reasonably well the removal of FC in a series of ponds as a whole.

Table 6.4 Values of the first order rate constant for faecal coliform removal at various temperatures (calculated from equation 6.13)

T(°C)	k_T(day^{-1})	T(°C)	k_T(day^{-1})
6	0.23	16	1.30
7	0.27	17	1.54
8	0.32	18	1.84
9	0.38	19	2.18
10	0.46	20	2.60
11	0.54	21	3.09
12	0.65	22	3.68
13	0.77	23	4.38
14	0.92	24	5.21
15	1.09	25	6.20

Maturation ponds require careful design to ensure that their FC removal follows that given by equations 6.12 and 6.13. If they are suboptimally loaded, then their FC removal performance may be correspondingly suboptimal (see Mills *et al.*, 1992).

Examination of equation 6.13 shows that it contains two unknowns, θ_m and n, since by this stage of the design process θ_a and θ_f will have been calculated, N_i measured or estimated (Section 6.2), N_e set (at, for example, 1000 per 100 ml for unrestricted irrigation; see Table 12.1) and k_T calculated from equation 6.13. The best approach to solving equation 6.12 is to calculate the values of θ_m corresponding to n = 1, 2, 3 etc. and then adopt the following rules to select the most appropriate combination of θ_m and n:

(a) $\theta_m \ngtr \theta_f$

(b) $\theta_m \ngtr \theta_m^{min}$

where θ_m^{min} is the minimum acceptable retention time in a maturation pond. This is introduced to minimise hydraulic short-circuiting and prevent algal washout. Marais (1974) recommends a value for it of 3 days, although at temperatures below 20°C values of 4-5 days are preferable.

The remaining pairs of θ_m and n, together with the pair θ_m^{min} and $\tilde{n}$, where $\tilde{n}$ is the first value of n for which θ_m is less than θ_m^{min}, are then compared and the one with the least product selected as this will give the least land area requirements. A check must be made on the BOD loading on the first maturation pond: this must not be higher than that on the preceding facultative pond, and it is preferable that it is significantly lower. In this Manual the maximum permissible BOD loading on the first maturation pond is taken as 75 percent of that on the preceding facultative pond. (It is not necessary to check the BOD loadings on subsequent maturation ponds as the non-algal BOD contribution to the load on them is very low.)

The loading on the first maturation pond is calculated on the assumption that 70 percent of unfiltered BOD has been removed in the preceding anaerobic and facultative ponds (or 80% for temperatures above 20°C). Thus:

$$\lambda_{S(m1)} = 10\ (0.3\ L_i)\ Q/A_{m1} \tag{6.14}$$

or, since $Q\theta_{m1} = A_{m1}D$:

$$\lambda_{S(m1)} = 10\ (0.3\ L_i)\ D/\theta_{m1} \tag{6.15}$$

The maturation pond area is calculated from a rearrangement of equation 6.10:

$$A_m = 2Q_i\theta_m/(2D + 0.001e\ \theta_m) \tag{6.16}$$

Design Example No. 3 in Annex I shows how maturation ponds are designed to produce an effluent suitable for unrestricted irrigation.

6.5.2 Helminth egg removal

Helminth eggs are removed by sedimentation and thus most egg removal occurs in anaerobic or primary facultative ponds. However, if the final effluent is to be used for restricted irrigation (see Section 12), then it is necessary to ensure that it contains no more than one egg per litre (Table 12.1). Depending on the number of helminth eggs present in the raw wastewater and the retention times in the anaerobic and facultative ponds, it may be necessary to incorporate a maturation pond to ensure that the final effluent contains at most only one egg per litre.

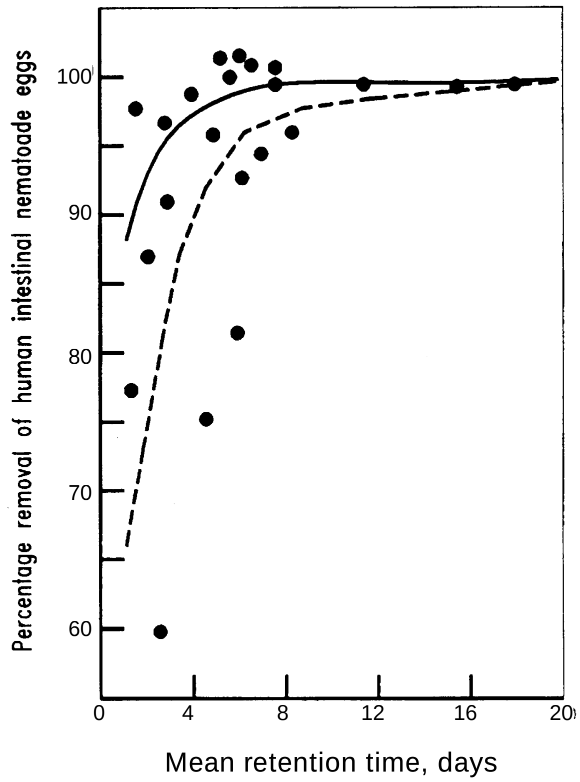

Figure 6.2
Variation of percentage helminth egg removal with retention time. Solid line: equation 6.17; dotted line, equation 6.18.

Analysis of egg removal data from ponds in Brazil, India and Kenya (Ayres *et al.*, 1992*a*) has yielded the following relationship (see Figure 6.2), which is equally valid for anaerobic, facultative and maturation ponds:

$$R = 100\ [1 - 0.14\exp(-0.38\theta)] \qquad (6.17)$$

where R = percentage egg removal
θ = retention time, d

The equation corresponding to the lower 95 percent confidence limit of equation 4.19 is:

$$R = 100\ [1 - 0.41\exp(-0.49\theta + 0.0085\theta^2)] \qquad (6.18)$$

Equation 6.18 is recommended for use in design (or Table 6.5 which is based on it); it is applied sequentially to each pond in the series, so that the number of eggs in the final effluent can be determined. An example of how it is used for restricted irrigation is given in Design Example No. 2 in Annex I.

6.5.3 BOD removal

Maturation ponds are not normally designed for BOD removal, yet it is often necessary to be able to estimate the BOD of the final effluent. BOD removal in maturation ponds is very much slower than in anaerobic and facultative ponds, and it is therefore appropriate to estimate the filtered BOD of the final effluent on the assumption of 90 percent cumulative removal in the anaerobic and facultative ponds and then 25 percent in each maturation pond (Mara and Pearson, 1987). The presence of algae in the final effluent often precludes the achievement of low concentrations of suspended solids and unfiltered BOD, and it may be necessary to include some simple algal removal system, such as rock filters (see Section 10.3), to meet strict effluent discharge standards.

Table 6.5 Design values of percentage helminth egg removal (R) in individual anaerobic, facultative or maturation ponds for hydraulic retention times (θ) in the range 1–20 days (calculated from equation 6.18)

θ	*R*	θ	*R*	θ	*R*
1.0	74.67	4.0	93.38	9.0	99.01
1.2	76.95	4.2	93.66	9.5	99.16
1.4	79.01	4.4	93.40		
1.6	80.87	4.6	94.85	10	99.29
1.8	82.55	4.8	95.25	10.5	99.39
2.0	84.08	5.0	95.62	11	99.48
2.2	85.46	5.5	96.42	12	99.61
2.4	87.72			13	99.70
2.6	87.85	6.0	97.06	14	99.77
2.8	88.89	6.5	97.57	15	99.82
3.0	89.82	7.0	97.99	16	99.86
3.2	90.68	7.5	98.32	17	99.88
3.4	91.45			18	99.90
3.6	92.16	8.0	98.60	19	99.92
3.8	92.80	8.5	98.82	20	99.93

6.5.4 Nutrient removal

There are very few data on nitrogen and phosphorus removal in WSP in the Region. For design recourse has to be made to equations developed in North America.

Nitrogen

Pano and Middlebrooks (1982) present equations for ammonical nitrogen (NH_3 + NH_4^+) removal in individual facultative and maturation ponds. Their equation for temperatures below 20ºC is:

$$C_e = C_i/\{1+[(A/Q)(0.0038 + 0.000134T)\exp((1.041 + 0.044T)(pH-6.6))]\} \quad (6.19)$$

and for temperatures above 20ºC:

$$C_e = C_i/\{1+[5.035 \times 10^{-3}\ (A/Q)][\exp(1.540 \times (pH-6.6))]\} \quad (6.20)$$

where C_e = ammoniacal nitrogen concentration in pond effluent, mg N/l
C_i = ammoniacal nitrogen concentration in pond influent, mg N/l
A = pond area, m^2
Q = influent flow rate, m^3/d

Reed (1985) presents an equation for the removal of total nitrogen in individual facultative and maturation ponds:

$$C_e = C_i \exp\{-[0.0064(1.039)^{T-20}]\ [\theta+60.6(pH-6.6)]\} \quad (6.21)$$

where C_e = total nitrogen concentration in pond effluent, mg N/l
C_i = total nitrogen concentration in pond influent, mg N/l
T = temperature, ºC (range: 1-28ºC)
θ = retention time, d (range 5- 231 d)

The pH value used in equations 6.19–6.21 may be estimated from:

$$\mathrm{pH} = 7.3\exp(0.0005\mathbf{A}) \qquad (6.22)$$

where **A** = influent alkalinity, mg $CaCO_3$/l

Equations 6.19 – 6.21 are applied sequentially to individual facultative and maturation ponds in the series, so that concentrations in the effluent can be determined. Design Example No. 4 in Annex I shows how these equations are used in the design of a wastewater-fed fishpond system (see also Section 12.4).

Phosphorus

There are no design equations for phosphorus removal in WSP. Huang and Gloyna (1984) indicate that, if BOD removal in a pond system is 90 percent, the removal of total phosphorus is around 45 percent. Effluent total P is around two-thirds inorganic and one-third organic.

6.6 PROCESS DESIGN *AIDE-MÉMOIRE*

This section is an *aide-mémoire* to WSP process design. It begins by asking about the destination of the final effluent.

A. Destination of final effluent

- Surface water discharge?
  If yes, go to **B**
- Crop irrigation?
  If yes, go to **C**
- Fish culture?
  If yes, go to **F**

B. Surface water discharge

- Determine effluent quality requirements (see Section 6.1) in terms of:
  BOD or COD, filtered or unfiltered
  Suspended solids
  Ammoniacal nitrogen
  Faecal coliforms
- Design an anaerobic* and facultative pond (Sections 6.3 and 6.4), and determine BOD, ammonia and faecal coliform levels in facultative pond effluent, as required (Sections 6.5.3, 6.5.4 and 6.5.1, respectively). If any of these are more than that required in the final effluent, design a maturation pond or ponds to reduce concentration(s) to required level (Section 6.5).

C. Crop irrigation

- Is there a local scarcity of water for irrigation such that the use of wastewater storage and treatment reservoirs (WSTR) (see Section 11) would be advantageous?

  If yes, go to **D**
  If no, go to **E**

D. WSTR

- Is the treated wastewater required for:
  - Restricted irrigation only?
    If yes, design an anaerobic pond* (Section 6.3) and a single WSTR (Section 11.1).
  - Unrestricted irrigation only?
    If yes, design an anaerobic pond* (Section 6.3) and 3-4 sequential batch-fed WSTR (Section 11.2).
  - Both restricted and unrestricted irrigation?
    If yes, design an anaerobic* and facultative pond (Sections 6.3 and 6.4) and a single WSTR – i.e. a hybrid WSP/WSTR system (Section 11.3). Note that, depending on the number of human intestinal nematode eggs in the raw wastewater, a maturation pond may be required after the facultative pond (see Section 11.3).

E. WSP

- Is the treated wastewater required for:
  - Restricted irrigation only?
    If yes, design an anaerobic* and facultative pond (Sections 6.3 and 6.4); check the number of human intestinal nematode eggs per litre of facultative pond effluent (Section 6.5.2); if > 1, design a maturation pond to reduce egg numbers to ≥ 1 per litre (Section 6.5.2)
  - Unrestricted irrigation only?
    If yes, design an anaerobic* and facultative pond (Section 6.3 and 6.4) and a series of maturation ponds to reduce the faecal coliform number in the final effluent to ≤ 1,000 per 100 ml (Section 6.5.1).
  - Both restricted and unrestricted irrigation?
    If yes, design as for Unrestricted irrigation above, but base the design of the maturation ponds on the flow required for unrestricted irrigation – i.e. the effluent of the facultative pond (or of the first maturation pond, if the numbers of human intestinal nematodes in the flow wastewater so dictate) is divided into two streams, one for unrestricted irrigation and the other for further treatment in maturation ponds prior to use for unrestricted irrigation.

F. Fish culture

- Follow the design procedure given in Section 12.4.

*** Note: anaerobic ponds** – check on sulphate concentration in raw wastewater and do not use anaerobic ponds if it is > 500 mg SO_4 per litre (or cannot be reduced to < 500 mg/l; see Sections 2.1.1, 3.2 and 5.5).