Annex 1
Wastewater-fed fish pond design

The design procedure given below for wastewater-fed fish ponds is based on the concept of *minimal* wastewater treatment in waste stabilization ponds for *maximal* production of microbially safe fish (Mara et al., 1993; Mara, 1997).

Waste stabilization ponds

Waste stabilization ponds are a low-cost (and usually the lowest-cost) wastewater treatment option. They comprise a series of anaerobic and facultative ponds, followed sometimes by one or more maturation ponds; however, in the case of minimal pretreatment prior to fish ponds, maturation ponds are not normally required. Both anaerobic and facultative ponds are simple earthen impoundments in which the wastewater is treated by natural processes for which no electrical energy is required.

In anaerobic ponds, the wastewater is treated by a combination of sedimentation and anaerobic digestion. Most trematode eggs settle out in this pond (the few that remain are removed in the receiving facultative pond).

Wastewater treatment in facultative ponds is "green treatment" achieved by the mutualistic growth of microalgae and heterotrophic bacteria (the profuse and entirely natural proliferation of the algae gives these ponds their characteristic intense green colour — hence the term "green treatment"). The algae produce oxygen from water as a by-product of photosynthesis. This oxygen is used by the bacteria as they aerobically bio-oxidize the organic compounds in the wastewater. An end-product of this bio-oxidation is carbon dioxide, which is fixed into cell carbon by the algae during photosynthesis (Figure A1.1). The permissible wastewater loadings on anaerobic and facultative ponds depend on temperature: the higher the temperature, the higher the permissible loadings. Retention times, which depend on both the wastewater flow and the wastewater loading, are relatively long: 1–3 days in anaerobic ponds and 4–10 days in facultative ponds, with minima of 1 and 4 days, respectively.

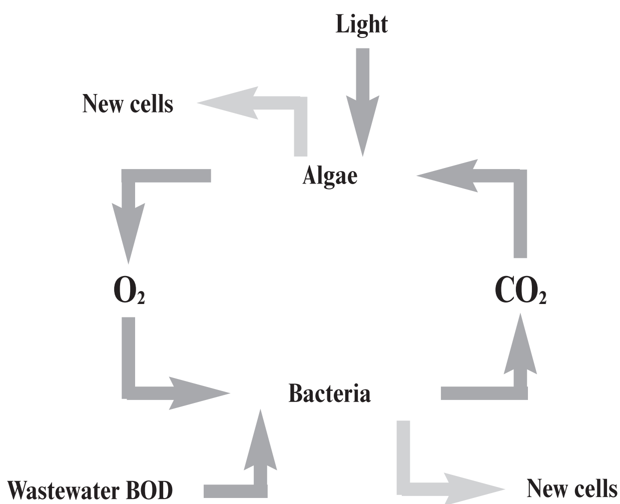

Figure A1.1
Bacterial–algal mutualism in facultative waste stabilization ponds

A fully descriptive online introduction to waste stabilization ponds for non-specialists is given by Peña Varón & Mara (2004).

Design procedure

The design steps are as follows:

1) Design a waste stabilization pond system comprising an anaerobic pond and a secondary facultative pond.
2) Determine the total nitrogen concentration in the effluent of the facultative pond.
3) Design the wastewater-fed fish pond, which receives the facultative pond effluent, on the basis of a surface loading of total nitrogen of 4 kg/ha per day (too little nitrogen results in a low algal biomass in the fish pond and consequently small fish yields; too much nitrogen gives rise to high concentrations of algae, with the resultant high risk of severe dissolved oxygen depletion at night and consequent fish kills).
4) Calculate the number of *E. coli* per 100 ml of fish pond water (this should be ≤1000 or ≤10^4 per 100 ml, as shown in Table 4.1).
5) Determine the concentration of free ammonia (i.e. dissolved NH_3 gas) in the fish pond (this should be <0.5 mg N/l in order to avoid acute toxicity to the fish).

A design example is given in Box A1.1.

Box A1.1 Wastewater-fed fish ponds: Design example

Design a fish pond that is to receive the effluent of a secondary facultative waste stabilization pond. The untreated wastewater flow is 1000 m^3/day, and it has a BOD of 200 mg/l, a total nitrogen concentration of 40 mg N/l and an *E. coli* count of 1 × 10^7 per 100 ml. The design temperature is 25 °C, and the net evaporation rate is 5 mm/day. [**Notes:** (a) "BOD" is the "biochemical oxygen demand," which is a common way of expressing the concentration of biodegradable organic matter in the wastewater; a BOD of *x* mg/l means that the concentration of biodegradable organic matter in the wastewater is such that the bacteria that bio-oxidize it in a wastewater treatment plant need *x* mg of O_2 per litre of wastewater bio-oxidized; (b) net evaporation = evaporation − rainfall.]

Full design details are given in Mara (2004).

A. Design of the anaerobic pond

The anaerobic pond volume (V_a, m^3) is given by:

$$V_a = Q\theta_a$$

where Q = wastewater flow (m^3/day) [here, = 1000 m^3/day]; and θ_a = the retention time in the anaerobic pond (days) [here, taken as 1 day, which is the minimum retention time permissible in an anaerobic pond]. Thus:

$$V_a = (1000 \times 1) = 1000 \text{ m}^3$$

This is equivalent, for a depth of 3 m, to an area of 333 m^2.

The BOD removal in an anaerobic pond at 25 °C is 70%, so the BOD of the anaerobic pond effluent (which becomes the influent to the secondary facultative pond) is (0.3 × 200) = 60 mg/l.

Box A1.1 (continued)

B. Design of the facultative pond

The facultative pond volume (V_f, m^3) is given by:

$$V_f = Q\theta_f$$

where Q = wastewater flow (m^3/day) [here, = 1000 m^3/day]; and θ_f = the retention time in the facultative pond (days) [here, taken as 4 days, which is the minimum retention time permissible in a facultative pond]. Thus:

$$V_f = (1000 \times 4) = 4000 \text{ m}^3$$

This is equivalent, for a depth of 1.5 m, to an area of 2667 m^2.

Reed's equation is used to determine the total nitrogen concentration in the effluent of the facultative pond (C_{Ne}, mg N/l) as follows, and assuming that there is no total nitrogen removal in the anaerobic pond:

$$C_{Ne} = C_{Ni} \exp\{-[0.0064(1.039)^{T-20}] \times [\theta_f + 60.6(\text{pH} - 6.6)]\}$$

where C_{Ni} = concentration of total nitrogen in the raw wastewater (mg N/l) [here, = 50 mg N/l]; T = design temperature (°C) [here, = 25 °C]; and the pH can be taken as 8. Thus:

$$C_{Ne} = 50 \times \exp\{-[0.0064(1.039)^{25-20}] \times [4 + 60.6(8 - 6.6)]\} = 25 \text{ mg N/l}$$

C. Design of the fish pond

The area of the fish pond (A_{fp}) is calculated on a design surface loading of total nitrogen ($\lambda_{s(N)}$) of 4 kg/ha per day, as follows:

$$A_{fp} = 10C_{Ni}Q/\lambda_{s(N)}$$

where C_{Ni} = total nitrogen concentration in the influent to the fish pond (i.e. in the effluent of the facultative pond) (mg N/l) [here, = 25 mg N/l]. Thus:

$$A_{fp} = (10 \times 25 \times 1000)/4 = 62\,500 \text{ m}^2 \text{ (6.25 ha)}$$

The retention time in the fish pond (θ_{fp}) is calculated taking the net evaporation into account, as follows:

$$\theta_{fp} = 2A_{fp}D_{fp}/(2Q - 0.001eA_{fp})$$

where D_{fp} is the liquid depth in the fish pond (m) [here, taken as 1 m]; and e is net evaporation (mm/day) [here, = 5 mm/day]. Thus:

$$\theta_{fp} = [2 \times 62\,500 \times 1]/[(2 \times 1000) - (0.001 \times 5 \times 62\,500)] = 74 \text{ days}$$

D. Check the* E. coli *count in the fish pond

The *E. coli* count in the fish pond (N_{fp}, per 100 ml) is calculated from the following equation (which takes into account its reductions in the anaerobic and facultative ponds):

$$N_{fp} = N_i/[(1 + k_T\theta_a)(1 + k_T\theta_f)(1 + k_T\theta_{fp})]$$

where N_i = the *E. coli* count per 100 ml of the untreated wastewater [here, = 1 × 10^7 per 100 ml]; and

k_T = the first-order rate constant for *E. coli* removal in ponds at T °C. Its value is given by:

$$k_T = 2.6(1.19)^{T-20} = 6.2\text{/day for } T = 25 \text{ °C}$$

Box A1.1 (continued)

Thus:

$$N_{fp} = (1 \times 10^7)/\{[1 + (6.2 \times 1)]\ [1 + (6.2 \times 4)]\ [1 + (6.2 \times 74)]\} = 120 \text{ per } 100 \text{ ml}$$

This is <1000 per 100 ml and therefore satisfactory.

E. Check the free ammonia concentration in the fish pond
The total ammonia concentration is the concentration of dissolved ammonia gas (NH_3) plus the concentration of dissociated ammonium ions. The percentage (p) of free ammonia in aqueous solutions depends on the in-fish pond pH and the absolute temperature (T, K), as follows:

$$p = 100/[10^{(pK_a - pH)} + 1]$$

where pK_a is given by:

$$pK_a = 0.09018 + (2729.92/T)$$

where T is the absolute temperature in Kelvin (K = °C + 273).

The pH in wastewater-fed fish ponds is ~7.5. Thus, for this pH and a temperature of 298 K (= 25 °C), these two equations give:

$$pK_a = 0.09018 + (2729.92/298) = 9.25$$

$$p = 100 / [10^{(9.25 - 7.5)} + 1] = 1.75\%$$

Thus, the free ammonia concentration (at this pH and temperature) is 1.75% of the total ammonia concentration. The total nitrogen concentration in the influent to the fish pond is 25 mg N/l; in the fish pond, it is less than this, and the total ammonia concentration in the fish pond is less than its total nitrogen concentration. Therefore, since 1.75% of 25 mg N/l is 0.44 mg N/l, the free ammonia concentration in the fish pond is less than this and thus below the toxicity threshold of 0.5 mg N/l.

Note: The total pond area is 6.55 ha, of which 0.3 ha is for the anaerobic and facultative ponds and 6.25 ha for the fish pond. The wastewater pretreatment ponds thus occupy only 5% of the total pond area. Thus, both subsistence and commercial fish farmers should always be encouraged to pretreat wastewater before using it to fertilize their fish ponds.

Fish yields

Good fish pond management can be achieved by having small ponds, preferably ≤1 ha, that can be stocked with fingerlings at the rate of $3/m^2$, fertilized with facultative pond effluent and then harvested three to four months after stocking. During this time, the fingerlings will have grown from ~20 g to ~200 g. Partially draining the pond will ensure that almost all the fish can be harvested. This cycle can be done 2 or 3 times per year (allowing for pond maintenance periods). Allowing for a 30% fish loss due to mortality, poaching and consumption by fish-eating birds, and assuming that the ponds (including the anaerobic and facultative ponds) are properly operated and maintained, the annual yield could be as high as 8–12 t of fish per hectare per year, although yields of 4–8 t of fish per hectare per year are more likely.

References

Mara D (1997). *Design manual for waste stabilization ponds in India*. Leeds, Lagoon Technology International Ltd.

Mara DD et al. (1993). A rational approach to the design of wastewater-fed fishponds. *Water Research*, 27(12):1797–1799.

Peña Varón MR, Mara DD (2004). *Waste stabilization ponds: thematic overview paper.* Delft, IRC International Water and Sanitation Centre (http://www.irc.nl/page/14622).