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RAPID COMMUNICATION

A RATIONAL APPROACH TO THE DESIGN OF WASTEWATER-FED FISHPONDS

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Abstract —A procedure is given for the minimal treatment of wastewater in a 1-day anaerobic pond followed by a 5-day facultative pond prior to discharge into a fishpond. The criterion for the design of the fishpond is a surface loading of total nitrogen of 4 kg N ha^{-1} d^{-1}. The number of faecal coliforms in the fishpond is then determined; this should be $\ngtr$ 1000 per 100 ml to ensure that the fish are microbiologically safe for human consumption. Fish (carp and tilapia) yields are of the order of 13 t ha^{-1} a^{-1}, assuming that the pond is drained and harvested three times a year and that there is a fish loss of 25 percent. Preliminary financial analysis indicates that such a wastewater-fed fishpond system is commercially viable.

Key words—lagooning, fish farming, design data, bacteria (faecal), removal, cost effectiveness.

INTRODUCTION

Fish raised in wastewater-fed ponds are an important source of animal protein for many millions of people in developing countries, particularly in eastern Asia. The largest example of wastewater-fed aquaculture in the world is at the Calcutta wetlands immediately to the east of the city (Edwards and Pullin, 1990): here, from some 3000 ha of fishponds fed with approximately 550,000 m^3 d^{-1} of untreated wastewater, around 13,000 tonnes of fish (mainly Indian major carp and tilapia) are supplied each year to the fish markets of central Calcutta, representing approximately 16 percent of the local demand for fish. The effluent from these fishponds is used for crop irrigation, and this is a common (and ecologically sensible) practice in many parts of the Region, for example China (Ruddle and Zhong, 1988).

However, the use of untreated wastewater to feed fishponds has the disadvantage that it may be difficult to ensure compliance with the current World Health Organization's guidelines for the microbiological quality of wastewater-fed fishponds (an absence of human trematode eggs and $\ngtr$ 1000 faecal coliform bacteria per 100 ml) (WHO, 1989). In this paper we present a design method for the minimal treatment of wastewater and the maximal production of microbiologically safe fish that effectively resolves the dilemma of simultaneously optimizing wastewater treatment and fish production in a practical way.

DESIGN METHOD

Design assumptions

These are based on typical conditions in West Bengal. A unit wastewater flow of 1000 m^3 d^{-1} is taken and the wastewater has a BOD_5 of 200 mg l^{-1} and 5 x 10^7 faecal coliforms (FC) per 100 ml. The design temperature and net evaporation rate are 25°C and 5 mm d^{-1}, respectively.

Minimal wastewater pretreatment

It is proposed that the wastewater be treated in an anaerobic and facultative pond. Since the wastewater is relatively weak (at least for a pond design temperature of 25°C), the design is based on mean hydraulic retention time (flow/volume) and, for example, would comprise a 1-d anaerobic pond and a 5-d facultative pond.

Anaerobic pond. Assuming a depth of 2 m, the mid-depth area of the anaerobic pond is given by (flow x retention time)/depth = (1000 x 1)/2 = 500 m^2. The volumetric BOD loading is (BOD_5 x flow)/(area x depth) = (200 x 1000)/(500 x 2) = 200 g m^{-3} d^{-1}, which is satisfactory since the maximum permissible design loading at 25°C is 300 g m^{-3} d^{-1} (Mara and Pearson, 1986).

Facultative pond. Assuming a depth of 1.5 m, the mid-depth area of the facultative pond is similarly calculated as (1000 x 5)/1.5 = 3340 m^2. The surface BOD loading, assuming a BOD_5 removal of 70 percent in the anaerobic pond, is given by (10 x BOD_5 x flow)/area = 10 x 0.3 x 200 x 1000/3340 = 180 kg ha^{-1} d^{-7}, which is satisfactory since the maximum permissible design loading at 25°C is 350 kg ha^{-1} d^{-1} (Mara, 1987). (Evaporation is not considered in the facultative pond design as, at short retention times, its effect is small: here, the area would be 3306 m^2, rather than 3340 m^2.)

Fishpond design

The most important criterion for the design of a wastewater-fed fishpond is total nitrogen loading. Too little nitrogen results in a low algal biomass in the pond and consequently small fish yields; and too much nitrogen gives rise to high concentrations of algae with the resultant risk of severe dissolved oxygen depletion at night and consequent fish kills. The optimal nitrogen loading is around 4 kg N ha^{-1} d^{-1} (Edwards, 1992). Little or no removal of total nitrogen occurs in anaerobic ponds, but it is significant in facultative ponds and can be estimated by the equation given by Reed (1985):

$$C_e = C_i \exp\{-[0.0064(1.039)^{T-20}][\theta + 60.6(pH-6)]\} \quad (1)$$

where C_e and C_i are the total N concentrations in the facultative pond effluent and influent respectively, mg l^{-1}; T is the design temperature, °C; and θ the retention time, d. Taking C_i as 50 mg l^{-1} and the pH as 8 gives a value of C_e of 25 mg l^{-1}. Thus, for a surface loading on the fishpond of 4 kg N ha^{-1} d^{-1}, its mid-depth area is given by (10 x C_e x flow)/loading = 10 x 25 x 1000/4 = 62500 m^2. Taking the evaporation rate of 5 mm d^{-1} into account and assuming a depth of 1.5 m, the retention time in the fishpond is 92 d.

Faecal coliform numbers. The number of FC per 100 ml of fishpond water may be estimated by the method of Marais (1974):

$$N_p = N_i/(1 + k\theta_a)(1 + k\theta_f)(1 + k\theta_p) \quad (2)$$

where N_p and N_i are the numbers of FC per 100 ml in the fishpond and raw wastewater respectively; k is the first order rate constant for FC removal, d^{-1} $(=2.6(1.19)^{T-20})$; and θ_a, θ_f and θ_p are the retention times in the anaerobic, facultative and fishpond respectively. For $N_i = 5 \times 10^7$ per 100 ml and $k = 6.2$ d^{-1} at 25°C, N_p is given by

$$N_p = 5 \times 10^7/[1 + (6.2 \times 1)][1 + (6.2 \times 5)][1 + (6.2 \times 92)]$$

$$= 380 \text{ per 100 ml}$$

Thus the microbiological quality of fishpond water complies with the WHO recommendation of $\ngtr$ 1000 FC per 100 ml (and also, due to the sufficiently long retention times in the anaerobic and facultative ponds, with the recommendation of no human trematode eggs). In fact the attenuation of faecal coliform numbers in a fertile waste-fed fishpond is extremely rapid: Edwards *et al.* (1984) reported an initial reduction of 99 percent due to dilution which was followed by a further 99 percent reduction from 10^4 to 100 per 100 ml within only 30 h.

The hydraulic loading on the fishpond is (1000/6.25) = 160 m^3 ha^{-1} d^{-1} and the BOD_5 loading, assuming 80 percent removal in the anaerobic and facultative ponds together, is 6 kg ha^{-1} d^{-1}. Both values are close to those found in practice (Edwards, 1992).

Overall design

Thus, for the unit flow of 1000 m^3/d, the total pond area requirement is (500 + 3340 + 62500) = 66,340 m^2; of this only 3840 m^2 (6 percent) is used for wastewater treatment. Allowing for embankments (the 6.25 ha of fishpond would be best subdivided into 3-12 parallel units), the overall land requirement is of the order of 10 ha.

Anticipated fish yields

In Calcutta carp are stocked at around three fingerlings (*ca* 20g) per m^2 in ponds ranging in size from a few to several tens of hectares. Ponds are drained only infrequently (once every 3-4 years) but fish of about 150-250 g, the size most commonly consumed by low-income communities, are seined at varying frequencies starting about 3 months after initial stocking. Yields on the better managed farms have risen to 5-7 t ha^{-1} a^{-1}, but this is probably an upper limit using current technology. Tilapias breed naturally in the system ponds: although they comprise about 30 percent of total fish production, they constrain further increases in yield as they are difficult to harvest by seining and much of the population consists of relatively large, slow-growing fish which take up both food and space, contribute little to the overall fish yield and inhibit the growth of carp.

It is proposed that the single stock and single harvest strategy currently employed in the 2-3 stages of nursery ponds also be applied to the grow-out ponds. This would require smaller (0.5-1 ha) ponds that could be drained every 3-4 months to harvest all the fish and be turned around quickly. Assuming a carrying capacity of 5 t ha^{-1}, three cycles of fish per year stocked at the current size and density and harvested at 200 g would yield about 13 t ha^{-1} a^{-1}, allowing for a 25 percent loss due to mortality, consumption by fish-eating birds and poaching. This would be approximately 2 to 3 times that currently achieved in the Calcutta wastewater-fed fishpond system.

Cost effectiveness

The costs used in the following financial calculations are based on those observed in West Bengal in April 1993, and the discount rate employed is 10 percent which is the value currently used by the World Bank for project appraisal in India. Costs are expressed in Indian rupees (Rs) in lakhs (1 lakh = 100,000) (exchange rates: UK£1 = Rs 48.50, US$1 = Rs 33.50). Assuming land costs of Rs 1 lakh ha^{-1} and self-help construction costs of 3 lakhs ha^{-1}, the total capital costs of the 10 ha pond system would be Rs 40 lakhs. Initial equipment (fish nets, boat, van and bicycles) costs would be Rs 10 lakhs, giving a total set-up cost of Rs 50 lakhs. Operating costs comprise labour costs and the purchase of fingerlings (stocking costs would, of course, be reduced substantially if the fish farmer raised his own fingerlings, as many do). Annual labour costs are estimated at Rs 2 lakhs (10 labourers at Rs 20,000 per year), and annual fingerling costs at Rs 2.8 lakhs (3 fingerlings m^{-2}, 62500 m^2, Rs 0.5 per fingerling, 3 times per year). Allowing Rs 0.5 lakh for equipment replacement, this gives total annual O & M costs of Rs 5.3 lakh. Fish farmers sell their fish for around Rs 18 kg^{-1}, so for an annual yield of 84 tonnes of fish the fish farmer's income would be Rs15 lakhs.

If the capital costs of Rs 50 lakhs were repaid over 10 years at an interest rate of 10 percent, this would entail an annual repayment of Rs 8.2 lakhs. With annual O & M costs of Rs 5.3 lakhs, the total annual costs for the 10 ha fishpond system would be Rs 13.5 lakhs. Thus, with annual fish sales of Rs 15 lakhs, the fish farmer would have a net annual income per 10 ha of Rs 1.5 lakhs (UK£3090, US$4480), which is 7.5 times that of an average labourer. The internal rate of return is 18 percent and the net present value at a discount rate of 10 percent over 10 years is Rs 13 lakhs. Clearly the wastewater-fed fishery system described herein is very cost effective.

CONCLUSIONS

1. The design approach for wastewater-fed aquaculture developed here is an effective way of achieving minimal wastewater treatment *and* maximal production of microbiologically safe fish for human consumption.

2. Such a wastewater-fed aquaculture system is a financially viable method of wastewater treatment and reuse in developing countries.

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REFERENCES

Edwards, P. (1992) *Reuse of Human Wastes in Aquaculture: a Technical Review*. Water and Sanitation Report No. 2. Washington, DC: The World Bank.

Edwards, P., Pacharaprakiti, C., Kaewpaitoon, K., Rajput, V.S., Ruamthaveesub, P., Suthirawut, S., Vomjinda, M. and Chao, C.H. (1984) *Reuse of Cesspool Slurry and Cellulose Agricultural Residues for Fish Culture*. AIT Research Report No. 166. Bangkok: Asian Institute of Technology.

Edwards, P. and Pullin, R.S.V. (1990) *Wastewater-fed Aquaculture*. Bangkok: Asian Institute of Technology.

Mara, D.D. (1987) Waste stabilization ponds: problems and controversies. *Water Quality International*, (1), 20-22.

Mara, D.D. and Pearson, H.W. (1986) Artificial freshwater environments: waste stabilization ponds. In: *Biotechnology*, vol. 8 (ed. W. Schoenborn), pp. 177-206. Weinheim: VCH Verlagsgesellschaft.

Marais, G.v.R. (1974) Faecal bacterial kinetics in waste stabilization ponds. *J. envir. Engng Div., Am. Soc. civ. Engrs*, **100** (EE1), 119-139.

Reed, S.C. (1985) Nitrogen removal in wastewater stabilization ponds. *J. Wat. Pollut. Control Fed.*, **57** (1), 39-45.

Ruddle, K. and Zhong, G. (1988) *Integrated Agriculture-Aquaculture in South China*. Cambridge: Cambridge University Press.

WHO (1989) *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture*. Technical Report Series No. 778. Geneva: World Health Organization.