1

Introduction

1.1 THE NEED FOR WASTEWATER TREATMENT

Wastewater needs to be adequately treated prior to disposal or reuse in order to:

(a) protect receiving waters from gross faecal contamination as they are often used as a source of untreated drinking water by downstream communities (or, in the case of coastal waters, used for shellfisheries);
(b) protect receiving waters from deleterious oxygen depletion and ecological damage; and
(c) produce microbiologically safe effluents for agricultural and aquacultural reuse (for example, crop irrigation and fishpond fertilisation).

As sewerage, both conventional and unconventional (the latter comprising simplified sewerage and settled sewerage (see Mara, 1996) which are more suitable for low-income communities), becomes more common in India, so too will the need for appropriate and sustainable wastewater treatment systems. Such systems need to be low cost, easy to operate and maintain, and very efficient in removing both organic matter (BOD) and the wide range of excreted pathogens present in wastewaters.

1.2 ADVANTAGES OF WASTE STABILIZATION PONDS

Waste stabilization ponds (WSP) are shallow man-made basins into which wastewater flows and from which, after a retention time of several days (rather than several hours in conventional treatment processes), a well-treated effluent is discharged. WSP systems comprise a series of ponds – anaerobic, facultative and several maturation. The different functions and modes of operation of these three different types of pond are described in Section 3 of this Manual. The advantages of WSP systems, which can be summarised as *simplicity, low cost* and *high efficiency*, are as follows:

Simplicity

WSP are simple to construct: earthmoving is the principal activity; other civil works are minimal – preliminary treatment, inlets and outlets, pond embankment protection and, if necessary, pond lining (further details are given in Section 5). They are also simple to operate and maintain: routine tasks comprise cutting the embankment grass, removing scum and any floating vegetation from the pond surface, keeping the inlets and outlets clear, and repairing any damage to the embankments (further details are given in Section 6). Only unskilled, but carefully supervised, labour is needed for pond O&M.

Low cost

Because of their simplicity, WSP are much cheaper than other wastewater treatment processes. There is no need for expensive, electromechanical equipment (which requires regular skilled maintenance), nor for a high annual consumption of electrical energy. The latter point is well illustrated by the following data from the United States (where one third of all wastewater treatment plants are WSP systems) for a flow of 1 million US gallons per day (3780 m^3/d) (Middlebrooks *et al*., 1982):

Treatment process	Energy consumption (kWh/yr)
Activated sludge	10,000,000
Aerated lagoons	8,000,000
Biodiscs	1,200,000
Waste stabilization ponds	nil

Thus the energy costs of activated sludge systems and aerated lagoons are very high. In Chennai, for example, total O&M costs, including energy costs, at the 23 Mld activated sludge plant at Nesapakkam are Rs 0.17 per m^3 of wastewater treated, equivalent to an annual cost of Rs 14 lakhs. With aerated lagoons it is not uncommon for the aerators to be permanently switched off as the energy costs are so high. The result is that the aerated lagoon then functions as an anaerobic pond. Provided this is recognised and the resulting anaerobic pond is not overloaded and regularly desludged (see Section 6.4), BOD removal efficiency can be as high as in the aerated lagoon but without, of course, the associated energy costs of the latter. A good example of an aerated lagoon operating satisfactorily as an anaerobic pond is at the Villivakkam wastewater treatment plant in Chennai.

The cost advantages of WSP were analysed in detail by Arthur (1983) in a World Bank Technical Paper. Arthur compared four treatment processes – trickling filters, aerated lagoons, oxidation ditches and WSP, all designed to produce the same quality of final effluent. Summary details are given in Box 1 on pages 4–6. The most important conclusion from Arthur's work is that WSP systems were the cheapest treatment process at land costs of US$ 50,000-150,000 (1983 $) per hectare, depending on the discount rate (opportunity cost of capital; range: 5-15 percent). These figures are much higher than most land costs likely to be encountered, and so land costs are unlikely to be a factor operating against the selection of WSP for wastewater treatment, although land availability may be. Arthur's economic methodology, which included both capital and O&M costs, is strongly recommended for use at the feasibility stage of all wastewater treatment projects in which a choice between different treatment processes has to be made. This should include, if necessary, the extra cost of conveying the wastewater to an area of low-cost land.

Tripathi *et al.* (1996) compared the costs of waste stabilization ponds, aerated lagoons, oxidation ditches and activated sludge for the treatment of domestic wastewater in India. The economic methodology used was broadly similar in principle to that used by Arthur (1983), but the WSP design procedure adopted (solar radiation principle for facultative ponds; 5 days retention for maturation ponds) is not now generally recommended (see Section 4). Activated sludge systems were found to be the most expensive option and WSP were the least cost system, although as expected the cost of WSP was highly dependent on the cost of land.

High efficiency

BOD removals >90 percent are readily obtained in a series of well-designed ponds. The removal of suspended solids is less, due

BOX 1

WASTEWATER TREATMENT COSTS

A recent World Bank report (Arthur, 1983) gives a detailed economic comparison of waste stabilization ponds, aerated lagoons, oxidation ditches and biological filters. The data for this cost comparison were taken from the city of Sana'a in the Yemen Arab Republic, but are equally applicable in principle to other countries. Certain assumptions were made, for example the use of maturation ponds to follow the aerated lagoon, and the chlorination of the oxidation ditch and biological filter effluents, in order that the four processes would have an effluent of similar bacteriological quality so that fish farming and effluent reuse for irrigation were feasible. The design is based on a population of 250,000; a per caput flow and BOD contribution of 120 litres/day and 40 g/day respectively; influent and required effluent faecal coliform concentrations of 2×10^7 and 1×10^4 per 100 ml, respectively; and a required effluent BOD_5 of 25 mg/litre. The calculated land area requirements and total net present cost of each system (assuming an opportunity cost of capital of 12 per cent and land values of US\$ 5/m^2) are shown in the Table opposite. Waste stabilization ponds are clearly the cheapest option.

The cost of chlorination accounts for US\$0.22 million per year of the operational costs of the last two options.

Clearly the preferred solution is very sensitive to the price of land, and the above cost of US\$ 5 per m^2 represents a reasonable value of low-cost housing estates in developing countries.

If the cost of land is allowed to vary, then the net present cost of each process varies as shown in Figure 1.1, for a discount rate (opportunity cost of capital) of 12 percent. Ponds are the cheapest option up to a land cost of US\$7.8 per m^2, above which oxidation ditches become the cheapest. In fact for discount rates between 5 and 15 percent the choice is always between WSP and oxidation ditches: the other two processes are always more expensive. Figure 1.2 shows the variation with discount rate of the land cost below which WSP are cheapest – between US\$ 5 and 15 per m^2 (US\$ 50,000 and 150,000 per ha).

Table 1.1 Costs and land area requirements of waste stabilization ponds and other treatment processes

	Waste stabilization pond system	Aerated lagoon system	Oxidation ditch system	Conventional treatment (biofilters)
Costs (million US$)				
Capital	5.68	6.98	4.80	7.77
Operational	0.21	1.28	1.49	0.86
Benefits (million US$)				
Irrigation income	0.43	0.43	0.43	0.43
Pisciculture income	0.30	0.30	-	-
Net present cost (million US$)	5.16	7.53	5.86	8.20
Land area (ha)	46	50	20	25

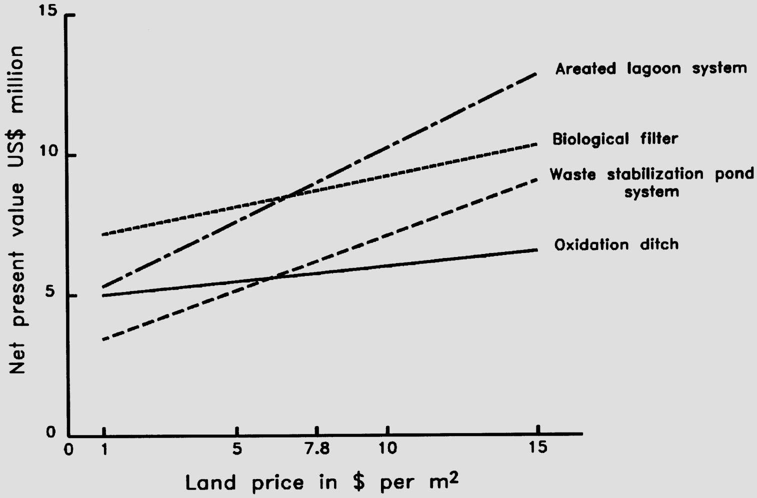

Figure 1.1 Variation in net present costs of the four treatment processes with land costs for a discount rate of 12 percent.

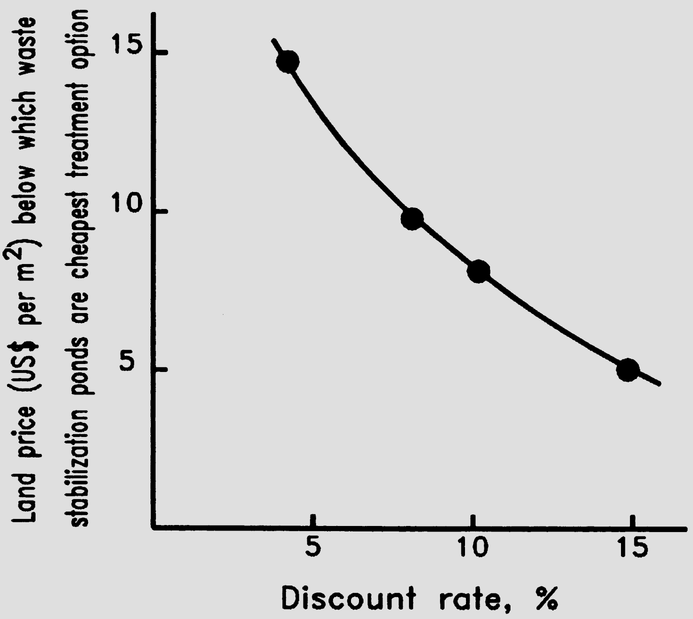

Figure 1.2 Variation with discount rate of land cost below which WSP are the least-cost treatment option.

to the presence of algae in the final effluent (but, since algae are very different to the suspended solids in conventional secondary effluents, this is not cause for alarm: see Section 4.1). Total nitrogen removal is 70-90 percent, and total phosphorus removal 30-45 percent.

WSP are particularly efficient in removing excreted pathogens, whereas in contrast all other treatment processes are very inefficient in this, and require a tertiary treatment process such as chlorination (with all its inherent operational and environmental problems) to achieve the destruction of faecal bacteria. Activated sludge plants may, if operating very well, achieve a 99 percent removal of faecal coliform bacteria: this might, at first inspection, appear very impressive, but in fact it only represents a reduction from 10^8 per 100 ml to 10^6 per 100 ml (that is, almost nothing). A properly designed series of WSP, on the other hand, can easily reduce faecal coliform numbers from 10^8 per 100 ml to $<10^3$ per 100 ml (the WHO guideline value for unrestricted irrigation; see

Section 10.1), which is a removal of 99.999 percent (or 5 $\log_{10}$ units).

A general comparison between WSP and conventional treatment processes for the removal of excreted pathogens is shown in Table 1.2; detailed information is given in Feachem *et al.* (1983).

Table 1.2 Removals of excreted pathogens achieved by waste stabilization ponds and conventional treatment processes

Excreted pathogen	Removal in WSP	Removal in conventional treatment
Bacteria	up to 6 log units[a]	1 – 2 log units
Viruses	up to 4 log units	1 – 2 log units
Protozoan cysts	100%	90-99%
Helminth eggs	100%	90-99%

[a] 1 log unit = 90 percent removal; 2 = 99 percent; 3 = 99.9 percent, and so on.

WSP are also extremely *robust*: due to their long hydraulic retention time, they can withstand both organic and hydraulic shock loads. They can also cope with high levels of *heavy metals*, up to 60 mg/l (Moshe *et al.*, 1972), so they can treat a wide variety of *industrial wastewaters* that would be too toxic for other treatment processes. Strong wastewaters from agro-industrial processes (for example, abattoirs, food canneries, dairies) are easily treated in WSP. Finally, WSP are the only secondary treatment process that can readily and reliably produce effluents safe for *reuse* in agriculture and aquaculture (see Section 10).

The principal requirements for WSP are that sufficient land is available and that the soil should preferably have a coefficient of permeability less than 10^{-7} m/s (to avoid the need for pond lining: see Section 5.2). The investment made by the sewerage authority in land for ponds can always be realised later. For example, the city of Concorde in California purchased land for ponds in 1955 at US$ 50,000 per ha, and by 1975 it was worth US$ 375,000 per ha (Oswald, 1976). Inflation during this 20 year period was exactly 100 percent, so the land increased in real value by 375 percent (or 6.8 percent per year).

1.3 ABOUT THIS MANUAL

This Manual is intended as a comprehensive guide for the design, operation and maintenance, monitoring and evaluation, and upgrading of WSP systems in India. Section 2 reviews WSP applicability and usage in India, and Section 3 provides a necessarily brief overview of the function and operation of each principal pond type.

The process design of the different types of pond (anaerobic, facultative and maturation) is described in detail in Section 4, and design examples are given in Annex I. Section 5 details the physical design of ponds and Section 6 their operation and maintenance requirements. Recommendations for routine effluent quality monitoring and WSP performance evaluation are given in Section 7.

Pond rehabilitation and upgrading is described in Section 8. Wastewater storage and treatment reservoirs, which are appropriate in arid and semi-arid areas when treated wastewater is in high demand for crop irrigation, are discussed in Section 9. Finally, Section 10 reviews the agricultural and aquacultural use of treated effluents, with emphasis on measures for the protection of public health.