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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 and so safeguard public health
(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) (see Khouri *et al.*, 1994).

Wastewater treatment needs to be appropriate and sustainable. It also needs to be least cost, easy to operate and maintain, and very efficient in removing both organic matter and the wide range of excreted pathogens present in wastewaters. In many (but obviously not all) situations in the countries covered in this Manual, waste stabilization ponds will be an especially suitable method of wastewater treatment.

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 2 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 7). 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 8). Less skilled labour is needed for pond O&M than is the case with other wastewater treatment technologies.

The simplicity of WSP construction also means that flexibility in construction phasing is possible. Whereas with conventional wastewater treatment processes all the reactors to treat the 20-year design flow are constructed initially, this is not the case with WSP. Provided all the land is purchased at the start, only those series required for the first 5 or 10 years need be built initially, with additional series being built as required in the future.

Low cost

WSP are normally less expensive than other wastewater treatment processes. There is no need for high-cost, 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 10 million US gallons per day (37,800 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

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 5–7. 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 $) (57,000–171,000 ecu) per hectare, depending on the discount rate (opportunity cost of capital; range: 5-15 percent). Arthur's (1983) economic methodology, which includes both capital and O&M costs, is still 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.

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).

WSP systems minimise sludge production and thus reduce the costs of, and the problems associated with, sludge handling, treatment and disposal (which can reach 55 percent of the O&M costs of activated sludge systems, for example). WSP desludging is not difficult (see Section 8.4) and sludge disposal can often be achieved on-site. WSP desludging is done every 1-3 years, in contrast to the daily handling, treatment and disposal of sludges produced at conventional wastewater treatment plants.

In France the mean capital costs of WSP systems serving populations up to 1000 are 800 FFR (120 ecu) per person with a range of 600-3000 FFR (90–450 ecu) per person (CEMAGREF *et al.*, 1997; see also Section 3.3). Burka (1996) estimated the costs of various methods of wastewater treatment for a population of 500 in rural Germany (Table 1.1). Even though cost levels in Germany are much higher than in Mediterranean countries, WSP were still competitive, costing around one-third the cost of activated sludge and about half that of reedbeds.

Table 1.1 Costs and land area requirements for various methods of wastewater treatment for a rural community of 500 population in Germany

Treatment process	Capital costs[a] (DM/person)	O & M costs[b] (DM/m^3)	Land area (m^2/person)
Activated sludge	2,000	2.00	0.3 - 1 plus 500%[c]
Trickling filter	1,500	1.70	0.4 - 1 plus 500%
Aerated lagoon	1,200	1.70	4 - 10 plus 100%
Vertical-flow reedbed	1,200	1.50	1.5 - 4 plus 100%
Horizontal-flow reedbed	1,500	1.30	6 - 8 plus 100%
WSP	700	1.20	10 - 15 plus 50%

[a] 1996 exchange rate: DM1 = 0.52 ecu.
[b] DM per m^3 of wastewater treated.
[c] Additional working area.

Source: Burka (1996).

High efficiency

Modern WSP design procedures (see Section 6) are able to ensure compliance with the effluent quality requirements of the EU Directive on urban wastewater treatment (Council of the European Communities, 1991) (see Section 6.1). BOD removals >90 percent are readily obtained in a series of well-designed ponds. 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 12.1), 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).

WSP are also extremely *robust*: due to their long hydraulic retention time, they are more resilient to both organic and hydraulic shock loads than other wastewater treatment processes. 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. Moreover, WSP are the only secondary treatment process that can readily and reliably produce effluents safe for *reuse* in agriculture and aquaculture (see Section 12). Finally, since WSP are designed for the coldest period of the year, and are more efficient in summer, they can accommodate an increase in population in the summer due to tourism.

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 7.2).

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.

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 Mediterranean countries. It thus extends the coverage of the WHO *Waste Stabilization Pond Design Manual for Mediterranean Europe* (Mara and Pearson, 1987). It takes into account recent developments in WSP technology and in particular places greater emphasis on wastewater storage and reuse in the Region. Section 2 provides a necessarily brief overview of the function and operation of each principal pond type, and Sections 3–5 review WSP usage in those parts of Mediterranean Europe, the Eastern Mediterranean and North Africa, respectively, where it is most developed.

The process design of the different types of pond (anaerobic, facultative and maturation) is described in detail in Section 6, and design examples are given in Annex I. Section 7 details the physical design of ponds and Section 8 their operation and maintenance requirements. Recommendations for routine effluent quality monitoring and WSP performance evaluation are given in Section 9.

Pond rehabilitation and upgrading is described in Section 10. 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 11. Finally, Section 12 reviews the agricultural and aquacultural use of treated effluents, with emphasis on measures for the protection of public health.

BOX 1

WASTEWATER TREATMENT COSTS

A World Bank report by 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 Table 1.3. 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).

Note: in 1983 the exchange rate was US$1 = 1.136 ecu.

BOX 1, continued

Table 1.3 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

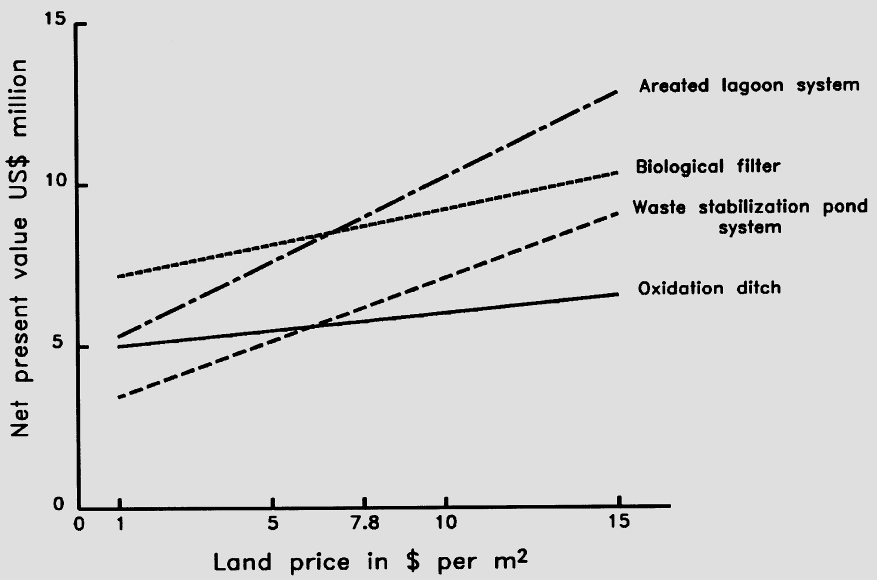

Figure 1.1 Variation in net present costs of the four treatment processes with land costs for a discount rate of 12 percent.

BOX 1, continued

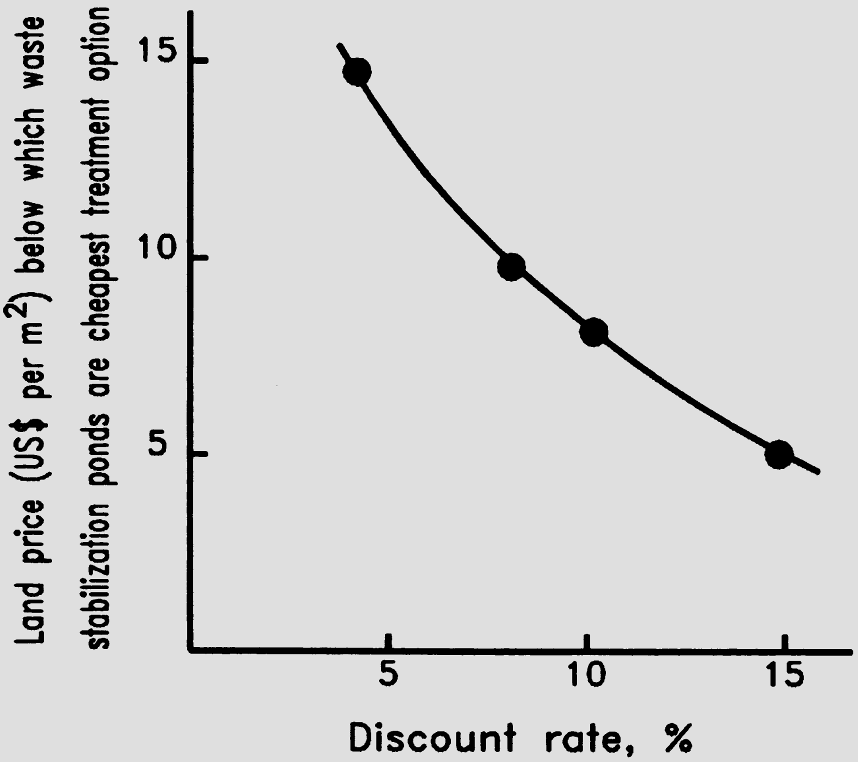

Figure 1.2 Variation with discount rate of land cost below which WSP are the least-cost treatment option.