7

Technical options for health protection

7.1 Introduction

The single most effective and reliable strategy for preventing transmission of disease caused by the use of human wastes is to treat the wastes according to the Engelberg quality guidelines (see Section 4.4). If this is done, disease transmission to those working in or living near the fields or ponds, and also to the crop-consuming public, either ceases or is reduced to a level of epidemiological insignificance.

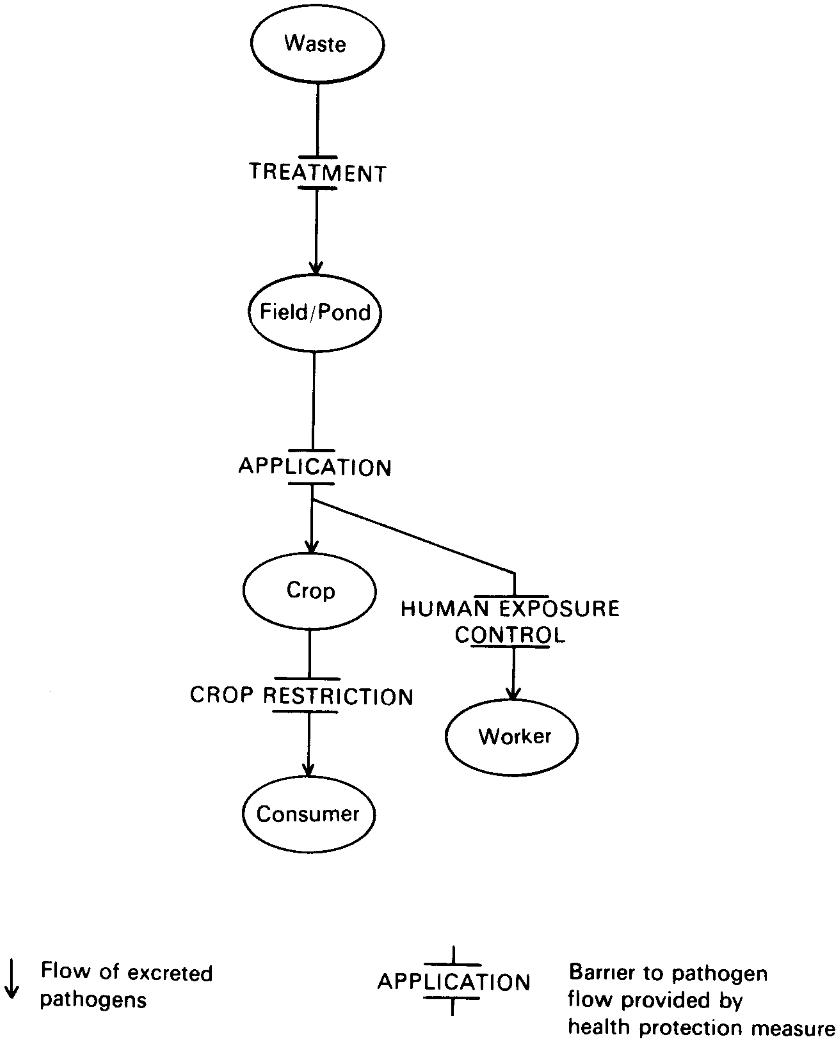
However, such thorough treatment may be expensive or unfeasible or may even be unnecessary since the presence of human pathogens in fields or ponds need not represent a health risk if other suitable health protection measures are taken. These measures may prevent pathogens from reaching the worker or the crop or, by selection of appropriate crops (cotton for example), may prevent any pathogens on the crop from affecting the consumer. The available measures for health protection can thus be grouped under four main headings:

- treatment of the waste;
- crop restriction;
- waste application methods;
- control of human exposure.

The points at which these measures can interrupt the potential routes of transmission of excreted pathogens are illustrated in Figure 7.1.

It will often be desirable to apply a combination of several methods. For example, crop restriction may be sufficient to protect consumers but will need to be supplemented by additional measures to protect agricultural workers. Sometimes, partial treatment to a less demanding standard may be sufficient if combined with other

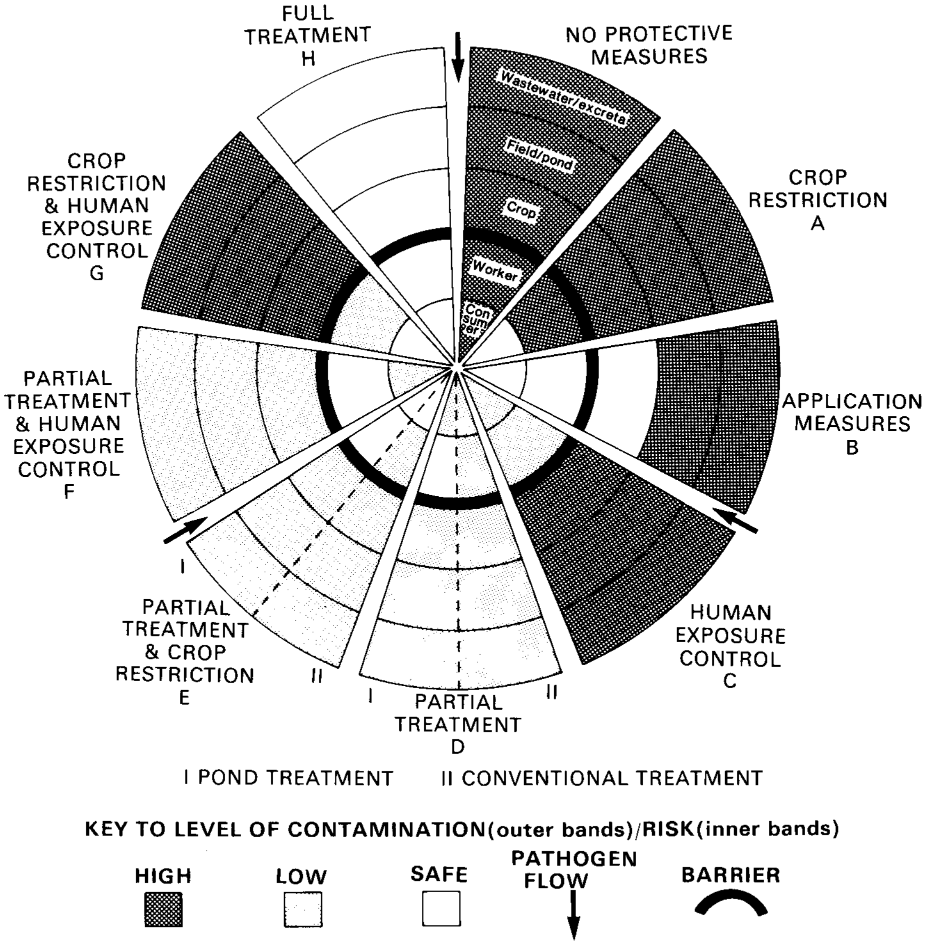
Figure 7.1 Effect of health protection measures in interrupting potential transmission routes of excreted pathogens



measures. The concept is illustrated in a schematic and simplified way in Figure 7.2, which shows three combinations that can successfully protect the health of both workers and consumers. The feasibility and efficacy of any combination will depend on many factors, which must be carefully considered before any option is put into practice. These factors will include the following:

- availability of resources (manpower, funds, land);

Figure 7.2 Generalized model to show the level of risk to human health associated with different combinations of control measures for the use of wastewater or excreta in agriculture or aquaculture



- existing social and agricultural practices;
- existing patterns of excreta-related disease.

For example, if funds or land are not available for wastewater treatment to the Engelberg guideline quality for unrestricted irrigation (see Table 4.5, page 79), some of the other three types of health protection measure will be needed. In some cases, suitable crop restriction can make it unnecessary to take any further measures to protect the public. On the other hand, if staff shortages and existing practices make it impossible to implement and enforce crop restrictions effectively, recourse must be made to other methods. In the case of aquacultural use, it will be possible to ignore the guideline for waste quality (see Table 4.7, page 89) if trematode infections are not found in the project area. Small-scale reuse schemes, especially for excreta, require special attention. They are often subsistence-level operations that are difficult to control and in which treatment is generally impossible; measures often need to be developed for minimization of risk to the individual, including health education and improved domestic water supplies.

The technical factors affecting each option are discussed below. Administrative and financial factors, which are equally important, are discussed in Section 8.

7.2 Wastes treatment

7.2.1 Objectives

The objective in treating wastewater or excreta for use in agriculture or aquaculture is to remove excreted pathogens and thus prevent disease transmission. However, this is not the purpose for which conventional wastewater treatment systems, normally used in Europe and North America, were originally developed. Their primary objective was the removal of organic matter, expressed in terms of their biochemical or chemical oxygen demand, and suspended solid material. In recent years, with increasing awareness of environmental pollution, sophisticated tertiary treatment processes have been added to conventional systems to improve pathogen removal. Waste stabilization ponds constitute a much simpler method of pathogen removal.

In considering pathogen removal from wastes, the number of pathogens surviving is more important than the number removed or killed. Figures such as 99% or 99.9% removal may seem very impressive, but they represent 1% or 0.1% survival respectively, and in view of the high concentrations of pathogens that can occur in the wastes, these proportions can be significant. Raw sewage may contain over 10^5 pathogenic bacteria per litre so that 99% removal would still leave over 10^3 pathogenic bacteria per litre.

The degree of removal by a waste treatment process is therefore best expressed in terms of $\log_{10}$ units: 99% removal is equivalent to two log units of reduction. From that perspective, there is only a trivial difference between a process that achieves 92% removal and one that removes 98%. Raw domestic wastewater typically contains about 10^7 faecal coliforms per 100 ml, and some 10^3 helminth eggs per litre where helminth infections are prevalent. To achieve the Engelberg guideline quality for unrestricted irrigation, therefore, a bacterial reduction of at least 4 log units and a helminth egg removal of 3 log units are required.

A lesser degree of removal can be considered if other health protection measures are envisaged or if the quality will be further improved after treatment. This can occur by dilution in naturally occurring water, by prolonged storage or by transport over long distances in a river or canal. The degree of pathogen reduction by dilution is easy to estimate, but the relevant figure to use is the minimum dilution, and this occurs in the dry season when stream flows are at their lowest. Pathogen reduction in reservoirs, rivers and channels is primarily a function of time and temperature and not necessarily of distance downstream. Pathogens in a fast-flowing natural stream may travel 50 km in little more than 12 hours, which is not likely to be sufficient time for any significant reduction in their numbers to occur.

7.2.2 Wastewater treatment

In the present context of wastewater reuse, the removal of excreted pathogens is the principal treatment objective. Efficient removal requires processes specifically designed for this purpose; incidental removal in other processes developed for other purposes is unlikely to be cost-effective (see Box 7.1). The removal of excreted pathogens in wastewater treatment processes has been reviewed in detail by Feachem et al. (1983). Table 7.1 summarizes the available information for the excreted bacteria and helminths and indicates where the Engelberg guidelines can be met. Degrees of removal of viruses and cysts are also given in Table 7.1, although these are not relevant to achievement of the Engelberg guidelines.

Conventional (primary and secondary) treatment

Raw wastewaters contain 10^7–10^9 faecal coliforms per 100 ml and it is clear from Table 7.1 that conventional processes (plain sedimentation, activated sludge, biofiltration, aerated lagoons and oxidation ditches) are not able, unless supplemented by disinfection, to produce an effluent that complies with the Engelberg guideline for bacterial quality ($<$ 1000 faecal coliforms per 100 ml).

Conventional wastewater treatment systems are not generally effective for helminth egg removal. There is a need for research and

Box 7.1 Wastewater treatment costs

A recent World Bank report 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 San'a in the Yemen Arab Republic. 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 a 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 capita flow and BOD_5 (biochemical oxygen demand measured on day 5 of treatment) 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 worth of each system (assuming an opportunity cost of capital of 12% and land values of US$ 5/m^2) are shown in the table below. The waste stabilization pond is the cheapest option. 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 for low-cost housing estates in developing countries.

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

	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 worth (million US$)	5.16	7.53	5.86	8.20
Land area (ha)	46	50	20	25

Source: Arthur (1983).

development work to improve the helminth egg removal efficacy of conventional systems to meet the Engelberg standards. Such processes as lime treatment, chemical coagulation and sedimentation, upward-flow anaerobic sludge blanket, sand filtration and storage in compartmentalized reservoirs deserve further study.

Table 7.1 Expected removal of excreted bacteria and helminths in various wastewater treatment processes

Treatment process	Removal ($\log_{10}$ units)			
	Bacteria	Helminths	Viruses	Cysts
Primary sedimentation				
Plain	0–1	0–2	0–1	0–1
Chemically assisted[a]	1–2	1–3 (E)	0–1	0–1
Activated sludge[b]	0–2	0–2	0–1	0–1
Biofiltration[b]	0–2	0–2	0–1	0–1
Aerated lagoon[c]	1–2	1–3 (E)	1–2	0–1
Oxidation ditch[b]	1–2	0–2	1–2	0–1
Disinfection[d]	2–6 (E)	0–1	0–4	0–3
Waste stabilization ponds[e]	1–6 (E)	1–3 (E)	1–4	1–4
Effluent storage reservoirs[f]	1–6 (E)	1–3 (E)	1–4	1–4

E—With good design and proper operation the Engelberg guidelines are achievable.
[a] Further research is needed to confirm performance
[b] Including secondary sedimentation
[c] Including settling pond
[d] Chlorination, ozonation
[e] Performance depends on number of ponds in series
[f] Performance depends on retention time, which varies with demand

Source: Feachem et al. (1983).

Waste stabilization ponds

Waste stabilization ponds are usually the wastewater treatment method of choice in warm climates wherever land is available at reasonable cost (Mara, 1976; Arthur, 1983). They should be arranged in a series of anaerobic, facultative and maturation ponds with an overall hydraulic retention time of 10–50 days, depending on the design temperature and the effluent quality required. Pond series can be readily designed to produce effluents that meet the Engelberg guidelines for both bacterial and helminthic quality; these effluents are also low in BOD and suspended solids (see Table 7.2).

The degree of bacterial reduction in a pond can be estimated from the formula:

$$R = 1 + Kt$$

where R is the ratio between the concentrations of faecal coliforms in the incoming and outflowing water; t is the retention time of the pond in days (i.e. its volume divided by the flow through it); and K is a factor representing the rate of die-off of faecal bacteria, which

Table 7.2 Performance of a series of five waste stabilization ponds in north-east Brazil (mean pond temperature: 26 °C)

Sample	Retention time (days)	BOD_5 (mg/l)	Suspended solids (mg/l)	Faecal coliforms	Intestinal nematode eggs (per litre)
Raw wastewater	–	240	305	4.6×10^7	804
Effluent from:					
Anaerobic pond	6.8	63	56	2.9×10^6	29
Facultative pond	5.5	45	74	3.2×10^5	1
Maturation pond 1	5.5	25	61	2.4×10^4	0
Maturation pond 2	5.5	19	43	450	0
Maturation pond 3	5.8	17	45	30	0

Source: Mara et al. (1983), Mara & Silva (1986).

depends on temperature. For maturation ponds, K can be estimated from:

$$K = 2.6\ (1.19)^{T-20}$$

where T is the mean temperature in °C. The mean monthly temperature of the coldest month of the year is normally used for design purposes (Mara, 1976). For facultative ponds, bacterial die-off rates are slightly slower. The degree of reduction in a series of ponds can be calculated from the fact that R_s for the series as a whole is simply the product of the values of R for the individual ponds:

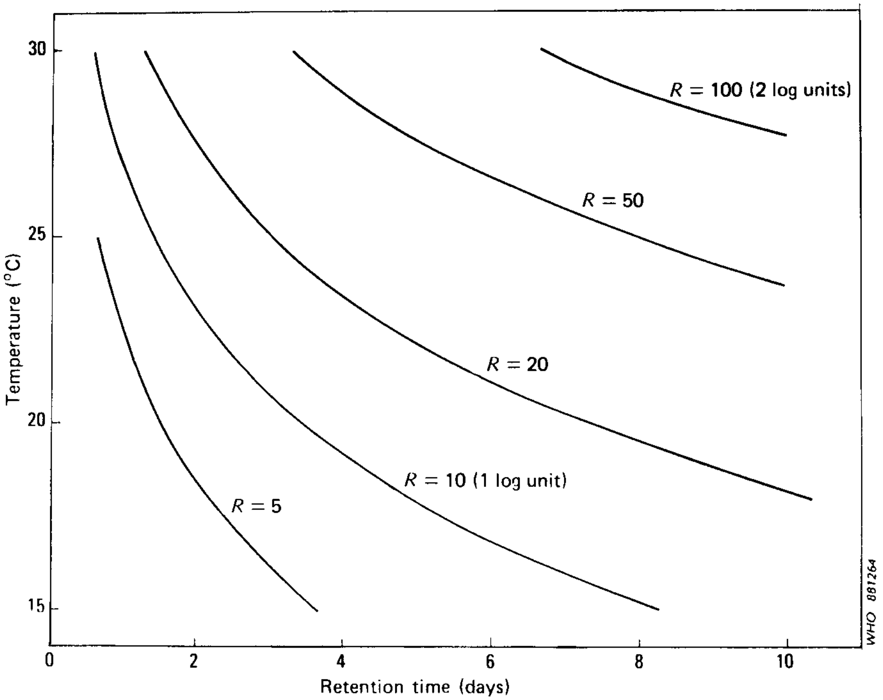
$$R_s = R_1 \cdot R_2 \cdot R_3 \cdot \ldots$$

The relationship between temperature, retention time and the reduction ratio R for a single pond is shown in Figure 7.3.

A number of ponds connected together in series will give better pathogen removal than a single pond with the same total retention time. Examples of the effluent quality that has been obtained in several series of ponds are given in Table 7.3. Each of these series had a total retention time of more than 25 days, but in many cases this could be reduced without jeopardizing the achievement of the Engelberg guideline.

Recent research in northeastern Brazil (Mara & Silva, 1986) has shown that the Engelberg guideline for helminths would normally be achieved by a series of three ponds — a 1-day anaerobic pond followed by a 5-day facultative pond and a

Figure 7.3 Reduction of faecal coliform bacteria in waste stabilization ponds as a function of time and removal



The reduction factor *R* is the number of faecal coliforms in the pond influent divided by that in the effluent

Table 7.3 Reported effluent quality for several series of waste stabilization ponds, each with a retention time > 25 days

Pond system	No. of ponds in series	Effluent quality (FC/100 ml)[a]
Australia, Melbourne	8–11	100
Brazil, Campina Grande[b]	5	30
France, Porquerolles	3	100
Jordan, Amman	9	30
Peru, Lima	5	100
Tunisia, Tunis	4	200

[a] FC = Faecal coliforms

[b] Experimental Centre for Biological Treatment of Wastewater (Extrabes).

Source: Bartone & Arlosoroff (1987).

5-day maturation pond. Such a series would, depending on temperature, reduce the faecal coliform concentration by only 2–3 $\log_{10}$ units, so that further maturation ponds would be necessary in order to achieve the Engelberg guideline of < 1000 per 100 ml. The size and number of the maturation ponds control the number of faecal coliforms in the final effluent of the pond series, and the design process (see Gambrill et al., 1986) specifically selects the optimum combination of maturation pond size and number required to achieve the desired final effluent quality.

The high degree of confidence with which pond series can be designed to produce effluents meeting the Engelberg guidelines is only one of the many advantages of pond systems. Others are:

- lower costs (for construction, operation and maintenance) than other treatment processes;
- no expenditure of energy (other than solar energy);
- high ability to absorb organic and hydraulic shock loads;
- extreme simplicity of operation and maintenance;
- ability to treat a wide variety of industrial and agricultural wastes.

The only disadvantage of pond systems is the relatively large area of land that they require, and this may limit their use, especially in metropolitan areas. Increasing pond depth is one method of reducing land area requirements, and recent research (Oragui et al., 1987; Mara et al., 1987) has shown that ponds 2–3 m deep can achieve degrees of bacterial and viral removal comparable to those in ponds of conventional depth (1–1.5 m). Further research is needed to determine other ways in which pond land area requirements can be minimized, for example by using ponds in conjunction with other more compact methods of treatment, such as soil/aquifer treatment. However, operation and maintenance requirements will be significantly more complex. In many situations, conventional pond systems are the best method of producing wastewater effluents suitable for crop irrigation.

Tertiary treatment

Tertiary treatment processes were originally developed to improve the quality of secondary (activated sludge or biofilter) effluents, mainly to reduce further the BOD and concentrations of suspended solids or to remove nutrients, although some processes (for example disinfection) were developed to reduce the number of excreted pathogens.

Processes designed to improve physicochemical quality — such as rapid sand filtration, nitrification-denitrification, and carbon adsorption — have little or no effect on excreted bacterial removal, but some of them (for example filtration) may be effective in removing helminths; further research is needed to provide reliable design data. However, these processes are usually complicated and expensive technologies, and their use in developing countries to produce suitable effluents for crop irrigation is unwarranted.

Disinfection

Disinfection — usually chlorination — of raw sewage has never been fully successful in practice. It can be used to reduce the numbers of excreted bacteria in the effluent from a conventional treatment plant if the plant is operating well. A chlorine dose of 10–30 mg/l is usually required, with a contact time of 30–60 minutes. The dose required must be verified by laboratory tests, as it varies widely with the concentration of organic matter in the waste.

However, as stressed by Chambers (1971): "Chlorination of wastewater effluents is a vastly more complex and unpredictable operation than chlorination of water supplies. It is extremely difficult to maintain a high, uniform and predictable level of disinfecting efficiency in any but the most efficiently operated waste treatment plants." For this reason it should not be considered a viable treatment option except where the highest levels of management and process control are guaranteed; irregular or inadequate disinfection is of little use for health protection. In any case, chlorination will leave most helminth eggs totally unharmed, and it is most unlikely that it will be effective in removing protozoal cysts (Feachem et al., 1983).

The environment produced by chlorination of treated effluent, rich in nutrients but low in microbiological activity, is ideal for the growth of some excreted bacteria. Coliforms and other species have been observed to multiply after chlorination to thousands of times the number surviving the initial treatment (Feachem et al., 1983). Effluent chlorination also contributes to the formation and environmental proliferation of chlorinated organic compounds that can be toxic to fish and other aquatic life (Water Research Centre, 1979). However, neither coliform regrowth nor chlorinated organic compounds have yet been reported as significant problems in agricultural use.

A more serious problem is the cost of chlorine — currently about US$ 1.00 per kilogram. Disinfection of the effluent from even a small treatment plant treating only 10 l/s of wastewater with a dose of 30 mg/l will cost about US$ 10 000 each year for the chlorine alone, without counting labour and equipment costs. For many countries, this is a cost in foreign exchange. Other disinfectants such as bromine and ozone may also be used, either alone or together with chlorine. These are usually more expensive still, and not much more effective.

Polishing ponds

A far more appropriate tertiary treatment option is to add one or more ponds in series to a conventional treatment plant. These are essentially the same as the maturation ponds in a series of waste stabilization ponds, and are designed in the same way to give the desired degree of removal of excreted bacteria and helminths. They are particularly suitable for developing countries, as they are reliable and require very little maintenance if they are competently designed and built. The maintenance tasks are simple and more akin to gardening than engineering.

The addition of polishing ponds is a suitable measure to upgrade an existing wastewater treatment plant (see Section 7.2.5).

Storage reservoirs

Demand for irrigation water is usually concentrated in the dry season or in particular periods of the agricultural year, while the flow of wastewater is relatively constant. Large reservoirs, often formed by damming existing watercourses, are therefore often used to store the wastewater until it is needed. Such storage reservoirs are used in Mexico and Israel (Shuval et al., 1986). Further treatment is achieved in such reservoirs, especially with regard to bacterial and helminthic qualities. At present there are insufficient field data on their performance to formulate a rational design process, but it is clear that pathogen removal will be enhanced by dividing them into compartments, connected in series, to reduce the degree of short-circuiting that can occur. The greater the number of compartments, and the longer the minimum retention time, the more efficiently pathogens will be removed.

For an undivided storage reservoir some degree of prior treatment will often be needed. An appropriately conservative design recommendation might be to provide a minimum hydraulic retention time of 10 days during the irrigation season, and to assume only two $\log_{10}$ units reduction of both faecal coliforms and helminth eggs. Thus the effluent being discharged into the reservoir should contain no more than 100 helminth eggs per litre and, if it is to be used for unrestricted irrigation, no more than 100 000 faecal coliforms per 100 ml during the irrigation season.

Physicochemical quality of treated wastewater

The physicochemical quality of treated domestic wastewaters, especially with regard to their electrical conductivity and sodium adsorption ratio (SAR), is normally within the limits for irrigation waters recommended by FAO (see Ayers & Westcot, 1985). Only if the ponds are treating a significant proportion of industrial wastewater is it necessary to check this and also to ensure that the final effluent does not contain harmful concentrations of phytotoxins, especially boron and heavy metals. In cases where treated wastewater has too high an SAR, consideration should be given to reducing it by blending the wastewater with a water (or wastewater) of a lower SAR; in such cases it is generally more appropriate to use the adjusted SAR (Ayers & Westcot, 1985).

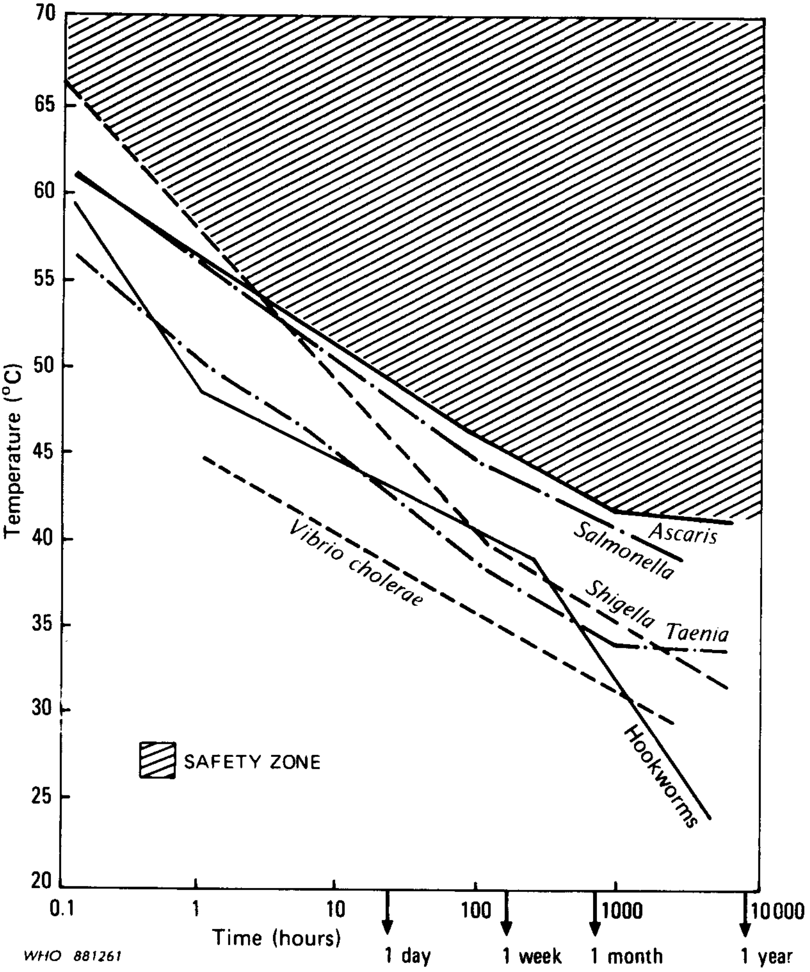
Removal of algae from pond effluents is not necessary (in the soil they act as slow-release fertilizers), except where localized irrigation is practised when they may exacerbate problems of clogging of emitters.

7.2.3 Excreta treatment

No treatment is required for excreta or excreta-derived products (such as septage or wastewater sludge) if they are applied to the land by subsurface injection, or placed in trenches before the start of the growing season, as described in Section 4.4.2. For other methods of land application, treatment is required to meet the Engelberg quality guidelines.

To achieve the guideline for helminthic quality (<1 viable intestinal nematode egg per 100 g), the excreta to be treated must be stored for a period of at least a year at ambient temperatures (see Figure 7.4). This period of storage refers to the whole time interval between excretion and land application, and so includes any time spent in a latrine pit, for example, or in a treatment process such as an

Figure 7.4 Influence of time and temperature on selected bacterial and helminthic pathogens in excreta and sludges



The lines represent conservative upper boundaries for pathogen death— this is, estimates of the time-temperature combinations required for pathogen inactivation. A treatment process with time-temperature effects falling within the zone of safety should be lethal to all excreted bacteria and helminths

From Feachem et al. (1983), reproduced by permission of the World Bank

anaerobic digester or a composting plant. This storage period may be reduced by treatment at a higher temperature, for instance in aerobic composting.

The contents of alternating twin-pit latrines (both ventilated improved pit latrines and pour-flush toilets) require no further treatment after removal from the pit before application to the land, provided that the latrine pits are emptied no more than once a year. Some types of double-pit latrine, such as those used in Guatemala and Viet Nam Guatemala, are normally emptied less than one year after they are filled and sealed. To ensure that the Engelberg guideline is met, the wastes would have to be stored for a further period to ensure that all the waste is at least one year old before use. *All* the contents of single-pit latrines, septic tanks, single-vault compost toilets and wastewater sludges must be stored after removal for at least a year, since there is no way of differentiating between freshly added excreta and that already digested.

Liquid nightsoil (faeces and urine, often with small quantities of toilet flush water) can be simply treated to meet the guidelines for helminthic quality by settlement. Conventional primary sedimentation is not appropriate, however, because of the high solids flux, and a more suitable method is storage for one week, after which the supernatant can be applied to the field. During this storage period, almost all the helminth eggs will settle, thereby posing little health risk to the farm workers who handle the supernatant. The one-week storage time can be readily assured if three storage tanks are available and used in a controlled sequence — one being filled, one undergoing quiescent settling and one in use. The sludge that settles to the bottom of the tank will be very rich in helminth eggs and should be considered in the same way as raw excreta and stored for a minimum period of one year or treated at high temperature. As none of this sludge should be applied directly to the field, simple methods to ensure this should be incorporated in the design of the storage tanks (for example, the installation of a grid just above the maximum sludge level).

Anaerobic mesophilic digestion followed by activated sludge or waste stabilization ponds is commonly used in Japan for treatment of nightsoil, although aerobic thermophilic digestion before activated sludge treatment is becoming more common. However, these are expensive, energy-intensive processes requiring careful operation and maintenance, and they are not generally appropriate in developing countries. A simpler alternative is the direct treatment of nightsoil and septage in waste stabilization ponds.

Elevated-temperature treatment of excreta

Two methods of treating excreta at high temperatures may be used to reduce the minimum storage period of 12 months. These methods will also ensure the removal of faecal coliforms, as well as of helminths, to the Engelberg standard:

(a) **Batch thermophilic digestion** at 50 °C for 13 days will ensure the inactivation of all pathogens. Batch digestion is required to avoid pathogen "shortcircuiting" — which is the term applied when detention times in reactors are lower than is necessary for pathogen inactivation.

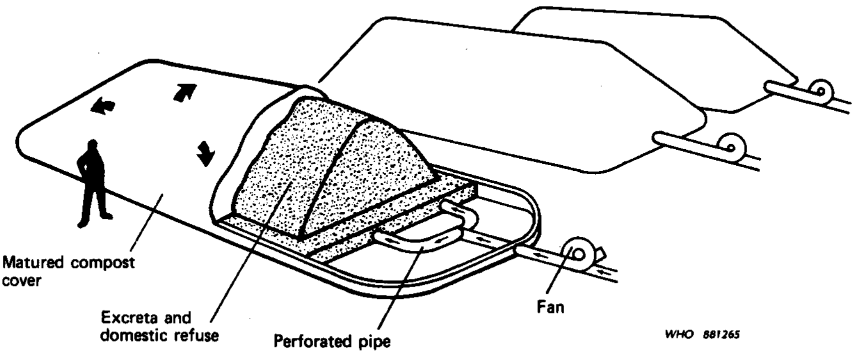
(b) **Forced aeration composting:** co-composting of excreta with domestic refuse in aerated static piles (see Figure 7.5) for one month will ensure that the temperature rises to 55–60 °C. Further maturation for 2–4 months at ambient temperature will produce a stable, pathogen-free compost suitable for general horticultural and agricultural use. Alternative bulking agents to domestic refuse, such as rice husks and wood chips, may be used, but from an environmental and municipal point of view domestic refuse is often the most suitable. Excreta may be composted without forced aeration (Gotaas, 1956), and this is likely to be the method of choice for small-scale operations, but pathogen destruction may not be as good or as reliable as with forced aeration (see Box 7.2).

Composting of excreta has several additional advantages:

- it avoids the nuisance of odour and flies associated with the storage and application to the land of raw excreta;

- it conserves nutrients;

Figure 7.5 Schematic diagram of forced aeration co-composting in static piles



Box 7.2 Forced aeration co-composting of excreta

Excreta (nightsoil) and wastewater sludges do not compost well by themselves: they are too moist and their carbon-to-nitrogen ratio is too low. A co-composting agent, able to absorb the excess moisture and correct the C:N ratio, must be added—for example, refuse, straw, rice husks.

Recent research (Stentiford & Pereira Neto, 1985; Pereira Neto et al., 1986; 1987) has developed the following simple procedure for co-composting:

Aerated pile phase

(*a*) The materials to be co-composted (20–50 mm in size) are mixed together to give a C:N ratio of 25–35 to 1 with a moisture content of 50–55%.

(*b*) The static pile is constructed over a length of perforated plastic pipe. Pile dimensions: 1.5–2 m high, 2–4 m wide and 10–50 m long. The pile is covered with an insulating and filtering layer of compost 100 mm thick.

(*c*) A fan of 250–370 W blows air through the pipe to maintain aerobic conditions within the pile. The fan is operated for 3–5 minutes every 15–20 minutes.

(*d*) As the temperature rises, the fan acts both to aerate the pile and to maintain a reasonably uniform distribution of temperature. Essentially it pushes heat from the hot inner core to the cooler outer edges, thus avoiding a heat build-up above 60 °C in the central core which would be detrimental to the thermophilic organisms responsible for the composting activity.

(*e*) The core and edge temperatures are monitored during this thermophilic phase; when they both fall to 35 °C, the pile is dismantled.

Maturation phase

(*f*) The material from the pile is stored for a further 2–4 months, depending on the ambient temperature, to allow humification of high-carbon compounds, such as lignin and cellulose, to be completed.

After maturation, the compost is screened to remove particles larger than 5–10 mm and it is then ready for agricultural or horticultural use.

- it prevents root damage induced by *in situ* stabilization of organic matter and the resulting free ammonia generation that occurs when raw excreta is applied to the land;
- mature compost helps to control plant pathogens;
- mature compost holds moisture and thus minimizes groundwater pollution, especially by nitrates; and
- soil structure is very much improved, and a fine tilth is easily achieved.

7.2.4 Treatment for aquaculture

Wastewater

For aquatic macrophyte culture, wastewater should be treated to the guideline quality of 0 trematode eggs per litre (see Table 4.7, page 89); this is readily achieved in waste stabilization ponds (see Section 7.2.2). Conventional effluents should be treated in a single polishing (maturation) pond of 5 days' retention time. For fish culture, wastewater should be additionally treated in maturation ponds or by disinfection to a level of less than 1000 faecal coliforms per 100 ml (see Section 4.4.3).

Excreta

Excreta should be treated to the same quality as wastewater. Storage at ambient temperatures renders trematode eggs inviable, and minimum storage periods are as follows:

Clonorchis sinensis	1 week
Fasciolopsis buski	3 weeks
Schistosoma spp	4 weeks

For small-scale operations the triple storage tank method may be used (see Section 7.2.3), but for larger schemes forced aeration composting or batch thermophilic digestion will generally be less expensive.

To achieve the guideline quality of less than 1000 faecal coliforms per 100 ml, excreta should be treated by composting or digestion, or in a series of facultative and maturation ponds with sufficient make-up water being added to replace evaporative losses and ensure an adequate flow through the system.

Pond maintenance

The control of snails, which are the first intermediate host of the trematodes that can be transmitted through aquaculture, can be achieved in fish-ponds by keeping the pond embankments free of vegetation. This vegetation would otherwise provide a suitable shaded habitat for both snails and culicine mosquitos (which may be the local vector of bancroftian filariasis). Such a strategy is not, of course, feasible in the case of macrophyte ponds, for which treatment is the only effective strategy (molluscicide dosing is unfeasible on grounds of cost). Mosquito breeding in macrophyte ponds should be controlled by the introduction of larvivorous fish such as *Gambusia* and *Poecilia.*

7.2.5 Upgrading existing treatment plant

Existing wastewater treatment works may need upgrading to produce an acceptable effluent. The provision of a polishing pond of 5 days' retention time (for helminth egg removal) or additional maturation ponds (for greater removal of faecal coliforms) is an effective solution if sufficient land is available. Alternatively disinfection or chemically assisted secondary sedimentation may be introduced; in the latter case lime or a lime-based coagulant has the advantage over other chemicals of killing faecal bacteria as well as removing helminth eggs, but the effluent pH must be adjusted to below 8.4 by cascade recarbonation or sulfuric acid.

7.3 Crop and fish restriction

7.3.1 Wastewater in agriculture

Wastewater that has been treated to the Engelberg quality guidelines for unrestricted use (< 1000 faecal coliforms per 100 ml and $\leqslant 1$ viable nematode egg per litre) can be used to irrigate any crop, without any further health protection measures. If this standard is not fully met, it may still be possible to grow selected crops without risk to the consumer. Some additional measures will be necessary to protect field workers and crop handlers and may also be required to give full protection to consumers.

Crops can be grouped into three broad categories with regard to the degree to which health protection measures are required (Shuval et al., 1986).

Category A—Protection needed only for field workers

1. Crops not for human consumption (for example cotton, sisal)

2. Crops normally processed by heat or drying before human consumption (grains, oilseeds, sugar-beet)

3. Vegetables and fruit grown exclusively for canning or other processing that effectively destroys pathogens

4. Fodder crops sun-dried and harvested before consumption by animals

5. Landscape irrigation in fenced areas without public access (nurseries, forests, green belts).

Category B—Further measures may be needed

1. Pasture, green fodder crops

2. Crops for human consumption that do not come into direct contact with wastewater, on condition that none must be picked off the ground and that spray irrigation must not be used (tree crops, vineyards, etc.)

3. Crops for human consumption normally eaten only after cooking (potatoes, eggplant, beetroot).

4. Crops for human consumption, the peel of which is not eaten (melons, citrus fruits, bananas, nuts, groundnuts)

5. Any crop if sprinkler irrigation is used (see Section 7.4.1).

Category C—Treatment to Engelberg "unrestricted" guidelines is essential

1. Any crops often eaten uncooked and grown in close contact with wastewater effluent (fresh vegetables such as lettuce or carrots, or spray-irrigated fruit)

2. Landscape irrigation with public access (parks, lawns, golf courses)

Irrigation that is limited to only certain crops and conditions, such as

Category A, is commonly referred to as restricted irrigation.

Crop restriction is a strategy for protection of the consuming public. It has the advantage of providing protection for population groups with lower resistance to infection, including those not part of the indigenous population such as tourists or pilgrims. However, it does not provide protection to the farm workers and their families where a low quality effluent is used in irrigation. Crop restriction is therefore not an adequate single control measure but should be considered within an integrated system of control. To provide protection for the workers as well as for the consumers, it should be complemented by other measures such as partial waste treatment, controlled application of the wastes, or human exposure control (see Figure 7.2).

Compliance only with the helminthic part of the Engelberg quality guideline would be a degree of partial treatment sufficient to protect field workers in most settings and would be cheaper than full treatment. For example, a pond system designed to meet only the helminthic guideline would require 52–67% of the land needed for one designed to reach the faecal coliform guideline, at temperatures of 20–25 °C.

Crop restriction is feasible and is facilitated in several circumstances, including the following:

- where a law-abiding society or strong law enforcement exists;
- where a public body controls allocation of the wastes, and has the legal authority to require that crop restrictions be followed;
- where an irrigation project has strong central management;
- where there is adequate demand for the crops allowed under crop restriction, and where they fetch a reasonable price;
- where there is little market pressure in favour of excluded crops (such as those in Category C).

However, where these circumstances do not prevail, crop restriction programmes will be difficult to enforce. Problems of implementing crop restrictions are further discussed in Section 8.

7.3.2 Excreta in agriculture

As in the case of wastewater irrigation, the restriction of excreta fertilization to Category A crops is a valid strategy for eliminating the health risks to consumers. Risks to field workers and crop handlers can be essentially eliminated by treating the excreta to the Engelberg helminthic quality or by applying it to the land in a suitable way (see Section 7.4.2). If excreta fertilization is used for Category C crops, treatment to the full Engelberg quality guideline is required. If this is not possible, water of a lower quality (but with not more than 10 000 faecal coliforms per 100 ml) may be used to fertilize Category B crops, provided that precautions are taken to control human exposure (see Section 7.5.1).

7.3.3 Aquaculture

Minimization of health risks through crop restriction is not as straightforward in the case of aquacultural use of excreta and wastewater as it is for agricultural use. Most cultured aquatic macrophytes and some fish are sometimes eaten raw in various parts of the world, notably parts of Asia, so that the agricultural option of not using excreta or wastewater for food crops, or for those consumed raw, is often not feasible—it would effectively mean the cessation of traditional aquacultural practices. The introduction of fish that are not eaten raw (for example tilapia) to such areas is a possible solution, but even so it is likely to be difficult to prevent customary practices completely, especially in small-scale subsistence aquaculture.

One practice that appears to be very promising is that of growing "trash" fish, such as tilapia, in excreta- or wastewater-fertilized ponds and feeding them to high-value fish (such as catfish, snakeheads) or crustaceans (shrimps, crayfish) that are reared in freshwater ponds. Insufficient research has been done to determine how contaminated the waste-reared fish may be without contaminating the freshwater-reared fish or crustaceans, but a conservative recommendation would be to grow the trash fish in ponds in which the faecal coliform count is no more than one order of magnitude greater than the guideline value given in Table 4.7 (that is $< 10\,000$ per 100 ml).

7.4 Application of wastewater and excreta

7.4.1 Wastewater in agriculture

Irrigation water, including treated wastewater, can be applied to the land in the five following general ways:

- by flooding (border irrigation), thus wetting almost all the land surface;
- by furrows, thus wetting only part of the ground surface;
- by sprinklers, in which the soil is wetted in much the same way as by rain;
- by subsurface irrigation, in which the surface is wetted little, if at all, but the subsoil is saturated; and
- by localized (trickle, drip or bubbler) irrigation, in which water is applied to each individual plant at an adjustable rate.

The general advantages and disadvantages of these irrigation methods and their suitability for different crops and ground slope conditions are fully discussed in an FAO paper (Doneen & Westcot, 1984), which should be consulted for further details. In specific relation to disease transmission control, the five methods of wastewater application have the advantages and disadvantages listed in Table 7.4. If the treated wastewater is of Engelberg guideline

Table 7.4 Factors affecting choice of irrigation method, and special measures required when wastewater is used

Irrigation method	Factors affecting choice	Special measures for wastewater
Border (flooding) irrigation	Lowest cost, exact levelling not required	Thorough protection for field workers, crop-handlers and consumers
Furrow irrigation	Low cost, levelling may be needed	Protection for field workers, possibly for crop-handlers and consumers
Sprinkler irrigation	Medium water use efficiency, levelling not required	Some Category B crops, especially tree fruit, should not be grown. Minimum distance 50–100 m from houses and roads. Anaerobic wastes should not be used because of odour nuisance
Subsurface and localized irrigation	High cost, high water use efficiency, higher yields	Filtration to prevent clogging of emitters.

quality, any of the five methods may be safely used, the choice between them being based on cost, water availability and ground slope.

If the water is not of this quality, but it is desired to use it on crops in Category B (see Section 7.3.1), sprinkler irrigation should not be used except for pasture or fodder crops, and border irrigation should not be used for vegetables.

Subsurface or localized irrigation can give the greatest degree of health protection as well as using water more efficiently and often producing higher yields (see Box 7.3). However, it is expensive and has not yet been used on a wide scale for irrigation with wastewater. A high degree of reliable treatment (usually involving both deep-bed and in-line filtration) is required to prevent clogging of the small holes (emitters) through which water is slowly released into the soil.

Bubbler irrigation, a technique developed for localized irrigation of tree crops (see Hillel, 1987), avoids the need for small emitter apertures to regulate the flow to each tree. A 6 mm diameter vertical riser tube is connected to the pipeline, through which water is distributed at low pressure. Each riser tube is supported if necessary by a small stake, and the top is cut off at a carefully chosen level to ensure an equal flow of water "bubbling" (or dribbling) from each tube, irrespective of variations in the ground level. The water runs into a small depression dug around each tree or bush.

If wastewater of lower quality is used, it is essential to follow the recommendations given in Section 7.5.1 for human exposure control in addition to the above restrictions.

Box 7.3 Trickle irrigation of cotton with pond effluent

A trickle system was installed in a cotton field to study the effects of pond effluent quality, emitter discharge and irrigation regime on the yield of cotton. The experiments were conducted in a typical arid zone (Beer-Sheva Valley, Israel) and the cotton was grown on loess soil. The results show that a high cotton yield of more than 6000 kg/ha can be obtained with the use of a high frequency (every 2 days) trickle irrigation system. A total of approximately 5900 m^3 of effluent per hectare was applied, with no additional fertilization required. With proper screen filtration no emitter clogging was observed.

Source: Oron et al. (1982).

7.4.2 Excreta in agriculture

Untreated or insufficiently treated excreta should only be applied to land by placing it in covered trenches before the start of the growing season (see Section 4.4.2), or by subsurface injection using specialized equipment (see Water Research Centre, 1984). Properly composted excreta can be manually or mechanically spread on land without any health risk as it is a pathogen-free material. Settled or thermophilically digested nightsoil may be applied either manually (by bucket and dipper, for example, as is common in China) or by tanker (which is often animal-drawn). The nightsoil, if treated only to the Engelberg guideline for helminthic quality, may contain high concentrations of bacterial and viral pathogens, and these will pose a greater risk to field workers than is the case for restricted irrigation with wastewater, which can only be minimized by exposure control.

7.4.3 Aquaculture

Before marketing, shellfish are commonly held in clean water to remove excreted organisms—a process known as depuration. Depuration is often recommended in excreta-fed aquaculture systems and can be carried out either by stopping application of the waste or by removing the fish to clean ponds. Keeping fish in clean water for at least 2 to 3 weeks before harvest will remove any residual objectionable odours and reduce the degree of contamination with faecal microorganisms. However, such depuration does not guarantee complete removal of pathogens from fish tissues and digestive tracts, unless the contamination is very slight.

7.5 Human exposure control

7.5.1 Agriculture

Four groups of people can be identified as being at potential risk from the agricultural use of wastewater and excreta. These are:

- agricultural field workers and their families;
- crop-handlers;
- consumers (of crops, meat and milk);
- those living near the affected fields.

Agricultural field workers are at high potential risk, especially of parasitic infections (see Section 4.3). Exposure to hookworm infection can be reduced, and even eliminated, by the continuous in-field use of appropriate footwear, but persuading workers to adopt this precaution may be difficult. A rigorous health education programme is needed. A similar approach may be taken with crop-handlers; the risk to them is somewhat less than that to field workers, but it can be reduced by meticulous personal hygiene and the wearing of gloves.

Immunization is not feasible against helminthic infections or against most diarrhoeal diseases. However, for highly exposed groups, immunization against typhoid and administration of immunoglobulin to protect against hepatitis A may be worth considering.

Additional protection may be provided by the availability of adequate medical facilities to treat diarrhoeal disease, and by regular chemotherapy. This might include chemotherapeutic control of intense nematode infections in children and control of anaemia. Chemotherapy must be reapplied at regular intervals to be effective. The frequency required to keep worm burdens at a low level (for example, as low as in the rest of the population) depends on the intensity of transmission, but will not normally be less than once a year. The drugs involved normally cost about US$ 0.50 for each complete treatment. One to three doses are required, depending on which drug is used.

Chemotherapy and immunization cannot normally be considered as an adequate strategy to protect farm workers and their families who are exposed to raw wastewater or excreta. However, where such workers are organized within structured situations such as government or company farms, these could be beneficial as palliative measures, pending improvement in the quality of the wastes used.

Risks to consumers can be reduced by the thorough cooking of vegetables and meat, by boiling milk, and by maintaining high standards of personal and kitchen hygiene. Food hygiene should be included in health education campaigns, although the efficacy of such campaigns may often be quite low in poorly educated societies or outside institutional settings.

Any risk of tapeworm transmission can be controlled by meat inspection provided that animals are slaughtered only in recognized abattoirs where all carcasses are inspected and all infected carcasses are rejected. Although *Taenia* eggs have been known to survive for several months on grazing land, the risk of bovine cysticercosis may be reduced by ceasing the application of the wastes at least two weeks before cattle are allowed to graze.

Wastewater irrigation of fruit trees should also cease two weeks before the fruit is picked.

Local residents should be kept fully informed about the location of all fields where human wastes are used, so that they may avoid entering them and prevent their children from doing so. Warning notices should be posted along the edges of fields, especially if there are no fences.

There is no epidemiological evidence that those living near wastewater-irrigated fields are at significant risk from pathogens present in aerosols from sprinkler irrigation schemes. However, steps should of course be taken to protect residents from direct wetting by droplets of spray from the sprinklers. For this reason, and allowing a reasonable margin of safety, sprinklers should not be used within 50–100 m of houses or roads. This minimum distance will often have to be increased for other reasons, for instance to minimize odour nuisance.

7.5.2 Aquaculture

There are four groups of people at potential risk from the aquacultural use of excreta and wastewater:

- aquacultural pond workers;
- fish- and macrophyte-handlers;
- fish- and macrophyte-consumers;
- those living near ponds fertilized with excreta or wastewater.

Many people will belong to more than one of these groups and thus be doubly at risk. The pond workers are at high potential risk, especially of parasitic infections.

Schistosomiasis is best dealt with by treatment of infected persons and by snail control (see Section 7.2.4). Where this is not possible, exposure to schistosomiasis can be controlled by the wearing of wellington boots or high-body waders (depending on the depth of the pond), but their use is rare and would interfere, for example, with the practice of harvesting lotus by loosening their roots with the toes. When all else fails, regular chemotherapy would be beneficial in endemic areas.

Local residents should be informed which ponds are fertilized with excreta or wastewater, so that they may prevent their children from playing or swimming in them. Warning notices should be posted by ponds adjacent to roads, especially if they are unfenced. However, where there is no adequate water supply or sanitation, local residents are likely to continue using the pond water for bathing, defecation and other purposes. Water supply and sanitation are therefore important measures for human exposure control.

Produce-handlers are at much less risk, and their exposure can be controlled by the wearing of gloves and the adoption of a high level of personal hygiene.

Attempts to alter traditional preferences for consuming aquacultural produce raw will not necessarily meet with success, and consumers are then best protected by proper treatment of the wastes before application.