6

Health Aspects of Sewage Systems

IN THIS CHAPTER the "wet" systems, which collect and treat excreta diluted by water, are considered. Not only conventional sewerage and sewage treatment systems are included, but also on-site sewage disposal methods such as septic tanks and aquaprivies. The reader wishing more technical information should refer to Kalbermatten and others (1982); Rybczynski, Polprasert and McGarry (1978); Mara (1976); Metcalf and Eddy, Inc. (1979); Okun and Ponghis (1975); and Tebbutt (1983).[1]

Aquaprivies and Septic Tanks

Aquaprivies and septic tanks are similar systems and are thus examined together. They both incorporate a sealed settling chamber in which solids accumulate and out of which an effluent flows.

Technical description

Septic tanks typically are located in the gardens of individual houses having water connections and full plumbing; they receive all wastewater from a house and have liquid retention times in the order of 1–3 days, after which the effluent normally goes to a soakaway. Aquaprivies are located directly under the toilet; they usually receive only excreta and small volumes of flushing water and have liquid retention times as high as 60 days, after which effluents flow to soakaways or into small-bore sewerage systems. In some designs aquaprivies also receive sullage, in which case retention times may decrease to a few days (depending on the volume of sullage produced). Designs for septic tanks and aquaprivies are shown in figures 6-1 and 6-2.

1. See also Part Two for a detailed review of the pathogen removal capabilities of the treatment systems examined in this chapter.

Pathogen survival

Two fundamental processes affecting pathogen removal in waste treatment operate in septic tanks and aquaprivies. First, solids settle to the sludge layer at the bottom of the chamber; with them settle any bacteria or viruses adsorbed onto the solids and any helminth eggs or protozoal cysts sufficiently dense to settle. The settling action of the tanks is their chief function and their efficiency depends on retention time and design (particularly with regard to baffles or compartments designed to prevent hydraulic short-circuiting and to create quiescent conditions). Those pathogens which do not settle will remain in the liquid layers and eventually pass out of the tanks in the effluent. The degree to which their concentration decreases depends on retention time and on their reaction to the rich, anaerobic liquor in which they are held.

Generalizations about pathogen removal in aquaprivies and septic tanks are difficult to make because designs and retention times vary enormously. Moreover, as the sludge layer of a septic tank builds up, retention times decrease and the pathogen content of the effluent increases. It is common to find operating aquaprivies and septic tanks that are long overdue for desludging; in these cases any good design features and pathogen removal abilities initially present will largely have been negated by the failure to desludge at the correct, regular intervals.

Because the quality of aquaprivy effluent depends greatly on retention time, the system is sensitive to variations in hydraulic loading. If the loading rate is too low and the water level is allowed to fall below the drop pipe, the result will be the release of offensive odor and, probably, large-scale mosquito breeding. Attempts to guarantee an adequate water level by running sullage into the tanks, however, will shorten retention times and raise the pathogen content of the effluent.

There are few available data on the quality of effluent from aquaprivy installations. The literature on septic

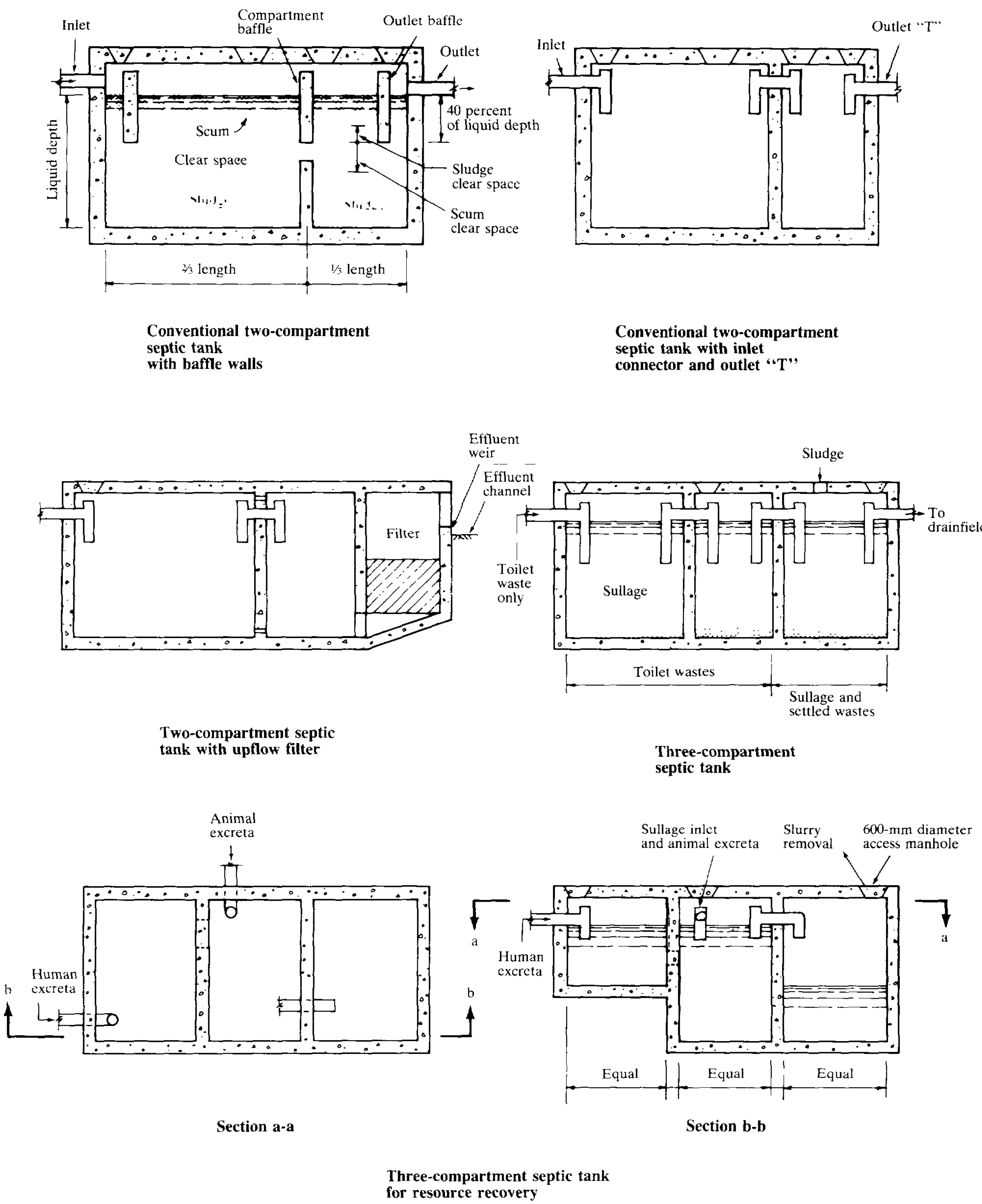
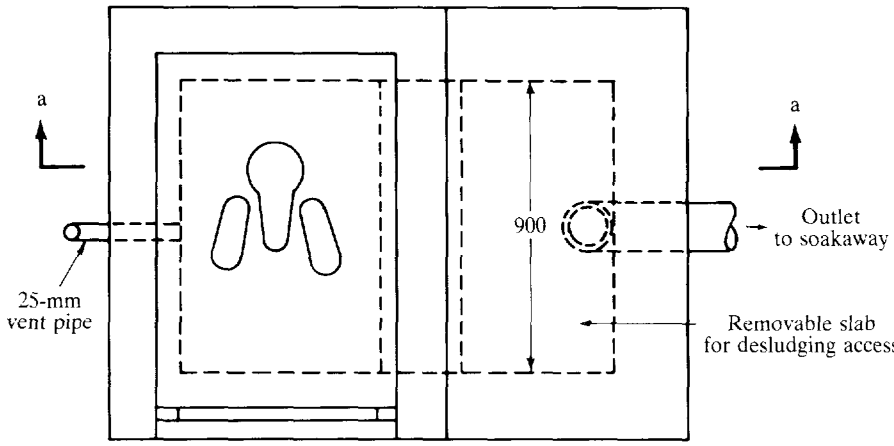
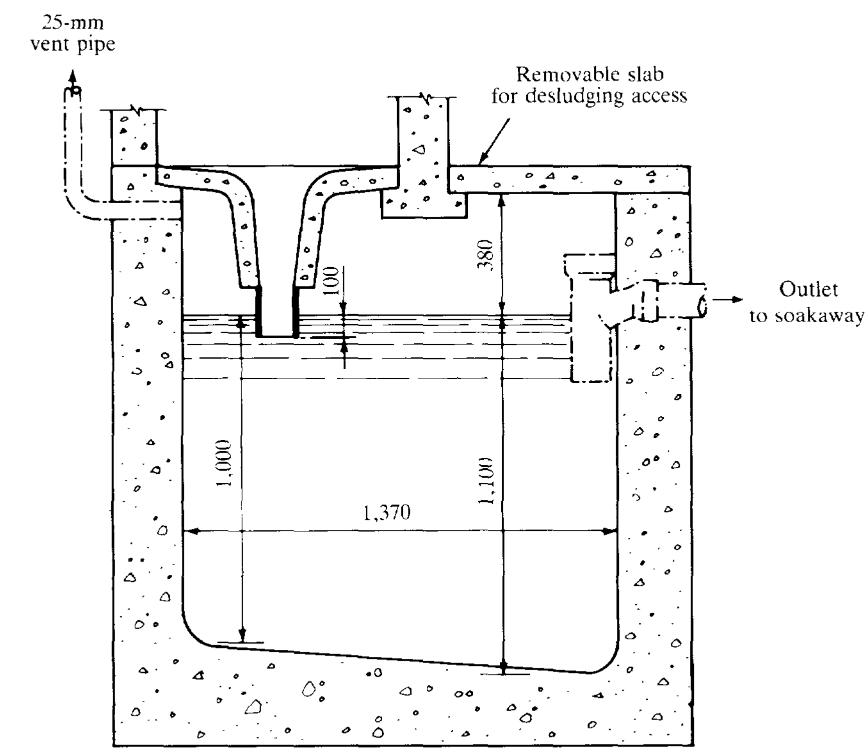


Figure 6-1. *Septic tank designs.* From Kalbermatten and others (1982)



Plan



Section a-a

Figure 6-2. *Conventional aquaprivy* (dimensions in millimeters). From Kalbermatten and others (1982); adapted from Wagner and Lanoix (1958) tanks, reviewed in detail in Part Two, will therefore be summarized here. In a septic tank having a normal retention time (1–3 days), the effluent produced will be rich in all pathogens contained in the influent. This flow is illustrated in figure 6-3. Removal of various types of pathogens from the effluent is as follows:

	Reduction (log_{10} *unit*)
Viruses	0–2
Bacteria	0–2
Protozoa	0–2
Helminths	0–2

Badly maintained and inadequately desludged tanks will have especially poor pathogen removal characteristics.

A proportion of all pathogens will settle, and fresh sludge will therefore contain significant numbers of pathogenic bacteria, viruses, protozoal cysts, and helminth eggs (figure 6-3). Whenever a septic tank is desludged, it is inevitable that some portion of the sludge will be fresh and, consequently, hazardous. Septic tank sludge should therefore be handled with great care and disposed of by burial, composting, or digestion (either aerobic or anaerobic) in the same way as any sewage sludge (and with the same effect on pathogens—see the previous chapter and the following section). A well-designed aquaprivy, with a longer retention time (>20 days) than a septic tank, may produce an effluent with only low concentrations of enteric bacteria, protozoa, or helminth eggs, and many of the viruses may settle when adsorbed onto solids. It is probable that an aquaprivy incorporating baffles and with a retention time this long will produce an effluent of substantially better quality than a normal septic tank (or, indeed, than a conventional sewage works). It must be assumed at present, however, that aquaprivy and septic tank effluents are highly pathogenic (figure 6-3). If they flow to sewers, they require treatment (probably in ponds) prior to any reuse. If they flow to soakaways, a groundwater pollution hazard may exist.[2]

Conventional Sewage Treatment

A variety of unit processes combine to form conventional sewage treatment; commonly used combinations are shown in figure 6-4. These component processes will be discussed in turn, followed by a discussion of the effects of a complete treatment works.

Pretreatment and primary sedimentation

Pretreatment by screening or comminution will have no effect on the pathogen content of sewage.

An almost universal first stage in conventional sewage treatment is the settling of suspended particles

2. See chapter 7, the section "Effluent Discharge. To groundwater."

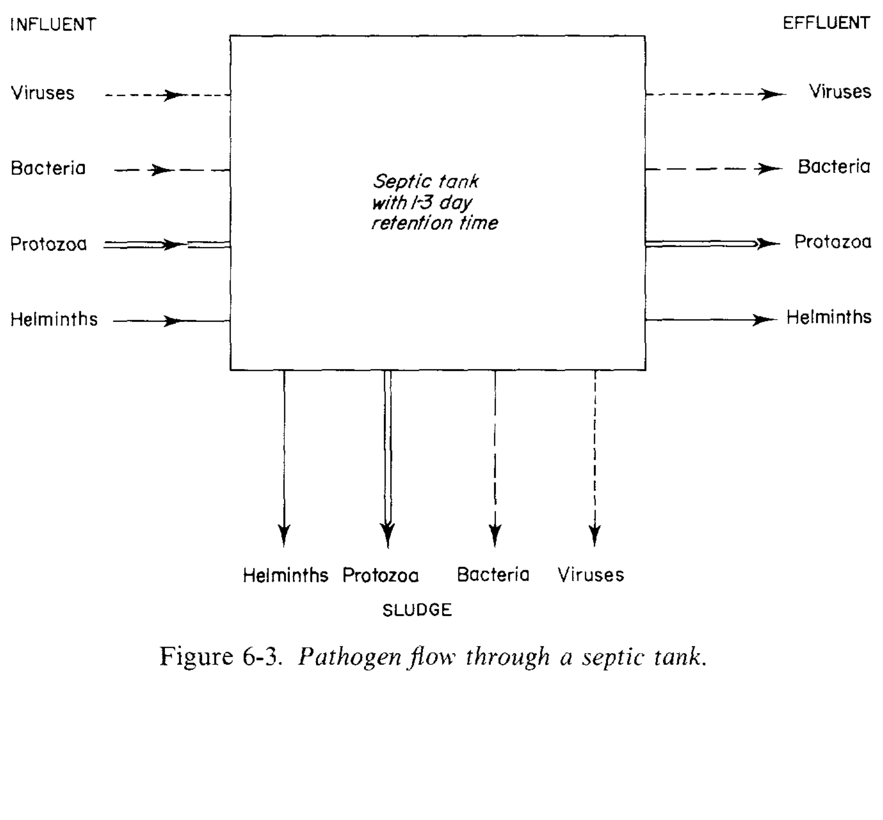


Figure 6-3. *Pathogen flow through a septic tank.*

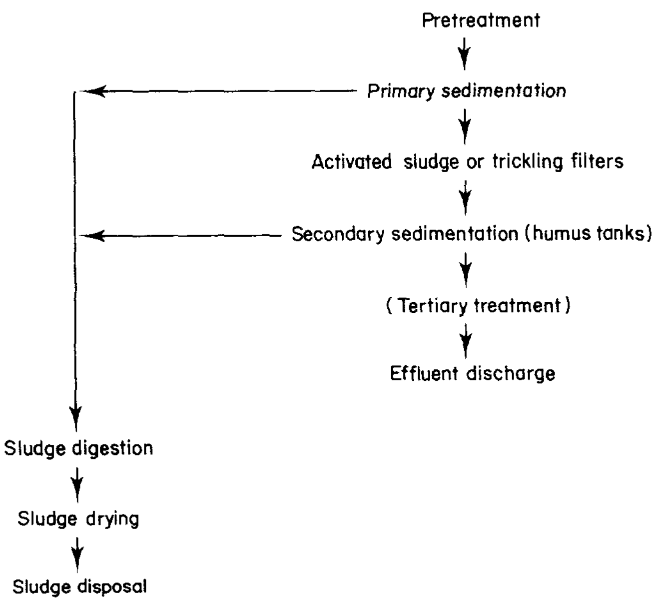


Figure 6-4. *Components of conventional sewage treatment*

in primary sedimentation tanks. A retention time in the tank of 2–6 hours is normal. A proportion of pathogens in the sewage will settle to the sludge layer either by direct sedimentation or by being adsorbed onto solids that are in the process of settling.

Many studies have found little or no virus removal by primary sedimentation, and in actual treatment works a removal rate of 50 percent seems to be a maximum. Bacterial removal by primary sedimentation may achieve 50–90 percent in 3–6 hours.

Shuval (1978) has collected data on the size and shape of eggs and cysts and has used these to compute the theoretical settling velocities shown in table 6-1. Actual settling velocities will be lower than these figures because in actual sedimentation tanks many factors hamper ideal settlement. The calculations indicate that only schistosomes, and maybe *Trichuris*, would have a reasonable degree of removal.

Studies on laboratory and full-scale primary sedimentation tanks have been done, but laboratory models always give higher removal efficiencies than actual plants because of more idealized and carefully controlled conditions.[3] *Entamoeba histolytica* cysts are reduced by 50 percent or less. Between 35 percent and 98 percent of helminth eggs settle, with 50–70 percent being the typical figure. Removal of various pathogens from the effluent is as follows:

	Reduction (log_{10} unit)
Viruses	0–1
Bacteria	0–1
Protozoa	0–1
Helminths	0–2

Similar performance may be expected from secondary settling tanks, except that these are often designed with higher overflow rates.

Flocculation of sewage (with ferric chloride, lime, or alum) will greatly improve the settlement of cysts and eggs and perhaps of other pathogens as well.

Trickling filters

Trickling filters alone do not appear to be efficient in removing viruses from sewage. Reductions reported

3. See Part Two, where the findings of such studies are reviewed.

Table 6-1. *Theoretical settling velocities of protozoal cysts and helminth eggs*

	Characteristics of Cysts and Eggs			
Pathogen	*Size* (micrometers)	*Density* (grams per cubic centimeter)	*Assumed shape*	*Settling velocity* (meters per hour)
Protozoa				
Entamoeba hartmanni	5	1.1	Spherical	0.007
Entamoeba histolytica	20	1.1	Spherical	0.11
Helminths				
Ascaris lumbricoides	55 × 40	1.11	Spherical	0.65
Hookworms[a]	60 × 40	1.055	Spherical	0.39
Schistosoma spp.	150 × 50	1.18	Cylindrical[b]	12.55
Taenia saginata	30	1.1	Spherical	0.26
Trichuris trichiura	50 × 22	1.15	Cylindrical	1.53

Source: Adapted from Shuval (1978).
a. *Ancylostoma duodenale* and *Necator americanus*.
b. *S. japonicum* eggs are spherical.

in the literature vary from 15 to 75 percent, with most results indicating 30–40 percent removal.[4]

Reductions in indicator bacteria in trickling-filter effluent vary between 25 and 99 percent. Typical reductions appear to be 80–95 percent. *Salmonella* reductions in the range of 71–99 percent are reported when removal by secondary sedimentation is included. The lower the loading rate on the filter, the higher the bacterial removal.

Many protozoal cysts and helminth eggs will pass through trickling filters. *Entamoeba histolytica* removal of 83–99 percent has been reported. Egg removal appears to be in the range of 20–90 percent, with higher reductions when the effect of secondary sedimentation is included.

Removal of various pathogens by trickling filters is as follows:

	Reduction (log_{10} unit)
Viruses	0–1
Bacteria	0–2
Protozoa	0–2
Helminths	0–1

Several studies of trickling filters have examined effluent after it has passed through a secondary sedimentation or humus tank. This tank may be expected to act as a primary sedimentation tank. Reductions in helminth eggs of 94–100 percent have been reported in combinations of trickling filters and humus tanks.

Activated sludge

Both laboratory data and field experience indicate that activated sludge systems are more effective in removing viruses than trickling filters.[5] Virus removals in activated sludge treatment works have been reported as up to 90 percent, although better results (up to 99 percent) are achieved in laboratory or pilot-scale models. In poorly maintained activated sludge plants, the finding of low virus removal rates is not unusual. Reductions of excreted bacteria are similar or a little better. Indicator bacteria removal rates are reported at up to 99 percent, but increases may occur. Pathogenic bacteria removal rates are commonly reported as between 60 and 99 percent at normal aeration times (6–12 hours), but may be as high as 99.9 percent following extended aeration for ⩾24 hours. The activated sludge process has little effect on protozoal cysts and helminth eggs, but substantial proportions of eggs will be removed in the secondary settling tanks. Complete activated sludge treatment plants have been reported to remove 80–100 percent of helminth eggs.

Considering the activated sludge process in isolation, pathogen removal efficiencies may be summarized as follows:

	Reduction (log_{10} unit)
Viruses	0–1
Bacteria	0–2
Protozoa	0–1
Helminths	0–1

Sludge digestion

It is clear from the discussion above that sludge from primary and secondary sedimentation tanks will contain a heavy load of excreted viruses, bacteria, protozoa, and helminth eggs. The fate of these pathogens depends on which of the many systems of sludge treatment is adopted. Anaerobic sludge digestion usually operates at one of three time-temperature combinations: 13 days at 50°C, 28 days at 32°C, or 120 days unheated. The first stage is often followed by a second-stage settling or thickening process, in which the sludge stands for a time similar to that of the first stage to allow the supernatant liquor to be drawn off.

If the digestion process is a batch process, thus ensuring that all the sludge has been at temperature x for time y, the following pathogen removal performances at the specified time-temperature combinations may be expected:

Combination	*Pathogens removed*
13 days at 50°C	All
28 days at 32°C	Viruses and protozoa: some bacteria and many helminth eggs remain
120 days unheated (in warm climate)	Protozoa: persistent helminth eggs (especially *Ascaris* and *Taenia*) and a few bacteria and viruses remain

But if the digesters are worked as a continuous process, with sludge being added and removed daily or more frequently, it is not possible to guarantee retention times, and pathogen survival will be appreciably higher than indicated above.

The expected pathogen removal characteristics of sludge treatments, as well as the effect of subsequent sludge thickening, are summarized in figures 6-5 and 6-6.[6] Protozoa will survive none of the digestion and

4. See Part Two for reports of pathogen removal by trickling filters.

5. Literature on the efficiency of activated sludge plants in removing excreted organisms is reviewed in Part Two.

6. See Part Two for a review of the literature on pathogen survival in sludge digestion.

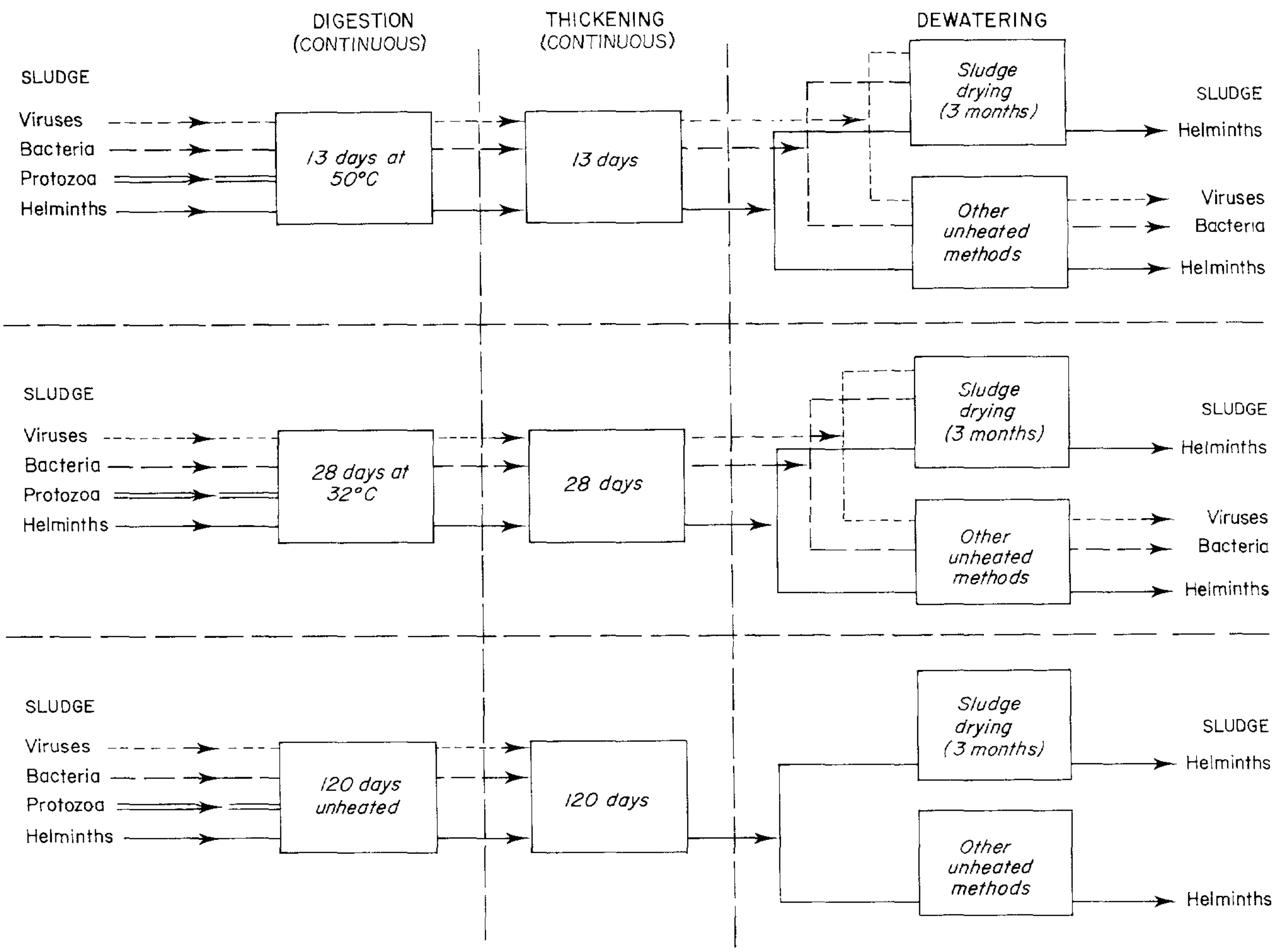


Figure 6-5. *Pathogen flow through various continuous sludge treatment processes*

thickening processes considered. Protozoal cysts are a feature of the effluents from conventional treatment plants and will not be found in treated sludges. With continuous operation, thermophilic digestion will leave small numbers of helminth eggs and excreted viruses and bacteria, whereas 120 days of unheated digestion in warm climates will leave only helminth eggs. The sole digestion process producing a thoroughly pathogen-free sludge is batch thermophilic digestion. Helminth eggs will always, and excreted viruses and bacteria will sometimes, be found in the sludges from all other digestion processes considered (Berg and Berman 1980).

Sludge dewatering

Figures 6-5 and 6-6 also illustrate the effect of sludge dewatering on digested sludges. Drying sludge in open beds for 2–3 months will remove the great majority, possibly all, of excreted viruses and bacteria at warm temperatures (>20°C). Protozoal cysts will be destroyed. Only persistent helminth eggs will survive in significant numbers, especially those of *Ascaris*, *Trichuris*, and *Taenia*.[7] Other unheated dewatering processes—such as vacuum filtration, pressure filtration, and centrifugation—will have little effect on pathogen content.

Other sludge treatment processes

Sludge may be composted with refuse, sawdust, woodchips, bark, straw or other material added to provide carbon, lower moisture content and improve texture. Thermophilic composting can achieve excellent pathogen removal and is discussed in the previous

7. The fate of various excreted pathogens during sludge drying is reviewed fully in Part Two.

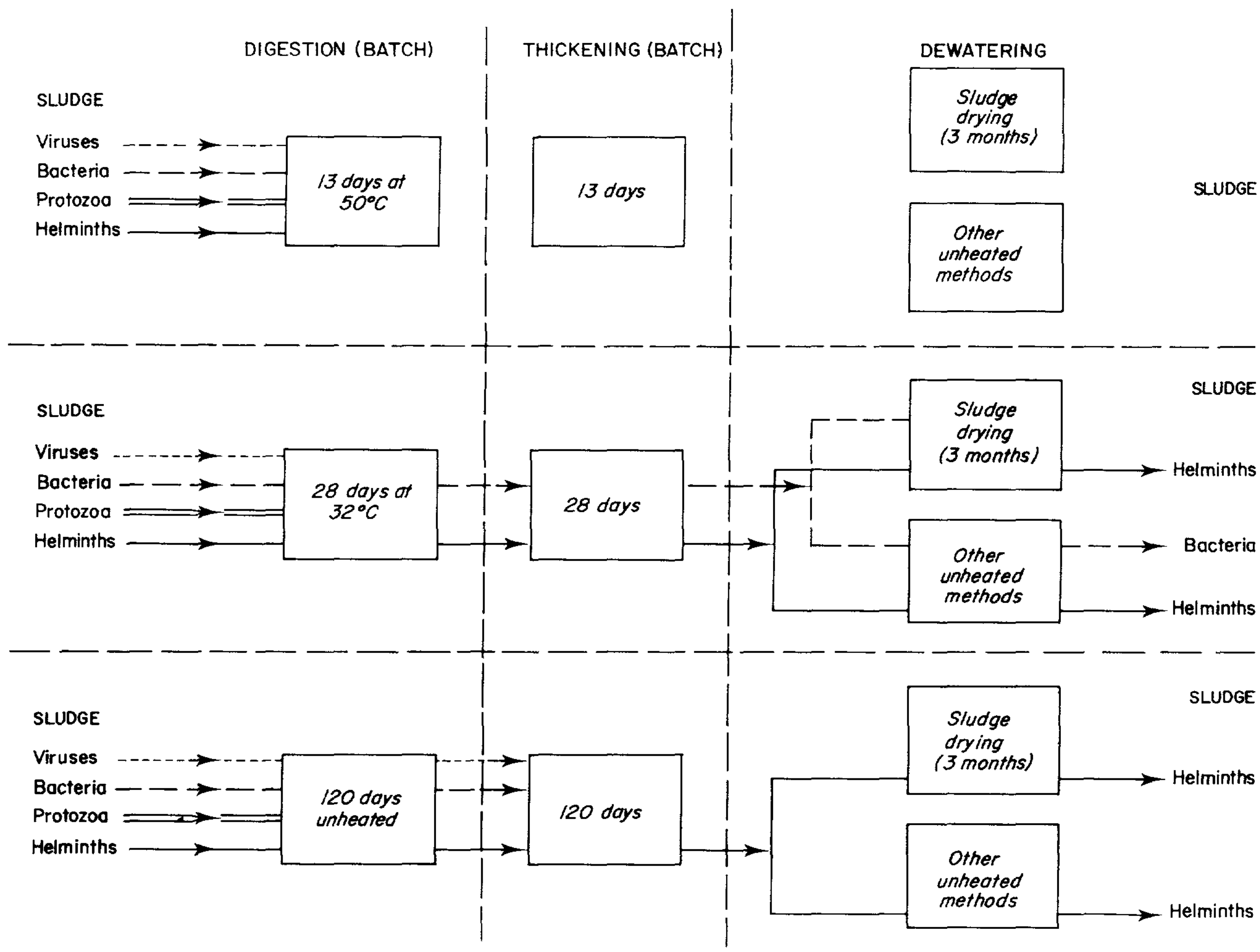


Figure 6-6. *Pathogen flow through various batch sludge treatment processes*

chapter (the section "Composting"). Several other sludge treatment processes are in use or under experimentation, but most of them are too technically complex and expensive to be appropriate for sludge treatment in developing countries. Those processes—such as wet oxidation (heating under pressure), pasteurization, incineration and pyrolysis—that involve temperatures of 80°C or above—produce a pathogen-free product (Osborn and Hattingh 1978). Sludge irradiation has attracted research interest and its effects on enteroviruses and fecal indicator bacteria are reviewed in chapters 9 and 13, respectively.

Complete treatment works

The effect on pathogens of the unit processes having been examined, the effect of their combinations in conventional sewage treatment can now be discussed.[8] First considered is a treatment plant featuring trickling filters and primary and secondary sedimentation.

The effluent from such a plant will contain significant concentrations of excreted viruses, bacteria, protozoa, and helminth eggs and is unsuitable for direct reuse in agriculture (see figure 6-7). It may often be unsuitable for discharge to freshwater where such bodies of water are used without treatment for domestic water supplies by downstream populations. The minimum retention time for liquids in the total plant may be around 5 hours, and this explains why the effluent—even if it is of adequate chemical quality (for instance, the effluent might conform to the established

8. The effect of conventional treatment plants on various pathogens is reviewed fully in Part Two.

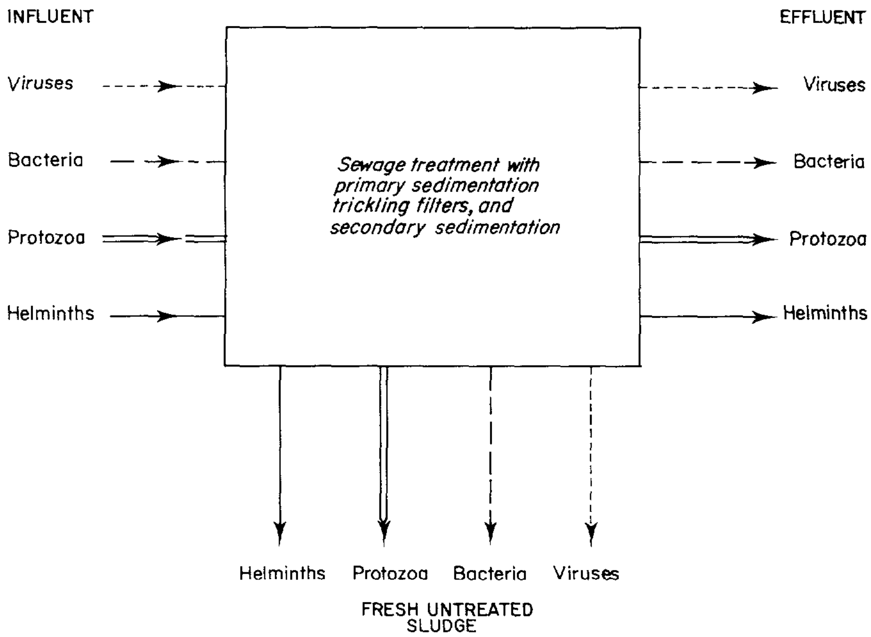


Figure 6-7. *Pathogen flow through a conventional sewage treatment plant featuring trickling filters*

physicochemical standard of <30 milligrams per liter of suspended solids and <20 milligrams per liter of standard biochemical oxygen demand, (BOD_5)—will be of poor microbiological quality. Effluent quality may be improved by using double filtration or recirculation, but the final effluent will still be highly pathogenic. The only way to produce an effluent of reasonably good quality from a health viewpoint is through certain tertiary treatment processes; even effluent chlorination may not be effective (see a discussion of both, below).

Effluents from activated sludge plants will be of marginally better quality than those produced by trickling filters but will still be heavily contaminated regardless of their chemical quality (see figure 6-8). The

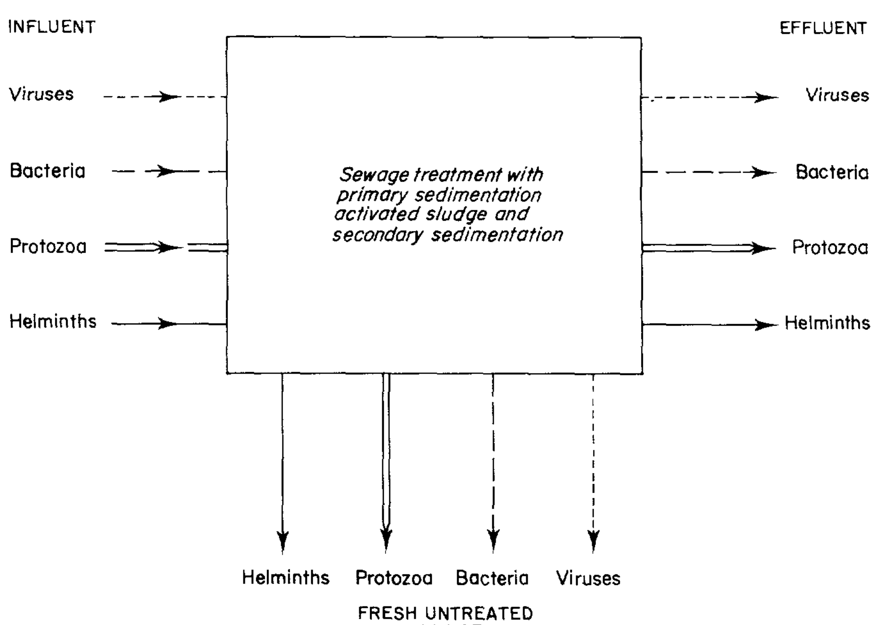


Figure 6-8. *Pathogen flow through a conventional sewage treatment plant featuring activated sludge*

minimum liquid retention time in the plant may be only 12 hours, and the final effluent will contain significant numbers of any pathogen found in the raw sewage. Tertiary treatment is indicated prior to reuse or prior to discharge into a river that downstream populations are using for water supplies.

The microbiological quality of the sludge depends on what treatment it receives. Fresh sludges from primary and secondary sedimentation tanks will contain pathogens of all kinds. Digestion at 50°C for 13 days will kill all pathogens, and digestion at 32°C for 28 days will remove protozoa and enteroviruses, provided that a batch process is used in both instances. Digestion for 120 days without heat in warm climates will remove all pathogens except helminth eggs, also only if a batch process is used. Continuous addition and removal of sludge will allow pathogens to pass through all processes. Sludge drying for at least 3 months in a warm climate is highly effective against all pathogens except helminth eggs. Other unheated dewatering techniques have little effect on the pathogenic properties of sludge.

The illustration of this somewhat complex situation in figures 6-5 and 6-6 shows that only a batch digester operated at 50°C will produce a pathogen-free sludge. Continuous digestion (as in practice) at 50°C may produce a sludge with excreted viruses and bacteria and helminth eggs if sludge drying beds are not used. All other alternatives will produce a sludge containing helminth eggs and some (such as mesophilic digestion followed by vacuum filtration) will produce a sludge with excreted viruses and bacteria as well.

The importance of temperature and time is clearly illustrated in figures 6-5 and 6-6. From a health viewpoint, the object of a sewage treatment works should be to retain all solids and liquids for the maximum time or to heat them to the maximum temperature feasible, or both. Batch processes are far more reliable in achieving this than continuous processes, and thought must be given to the design and economics of batch digesters in circumstances where sludge is to be reused in agriculture.

Aerated Lagoons

Aerated lagoons resemble small waste stabilization ponds with floating mechanical aerators, but they are more correctly considered as a simple modification of the activated sludge process. Reference to the section on activated sludge earlier in the chapter and to the section on stabilization ponds below, along with the description here, will clarify the specifics of this system.

Technical description

In aerated lagoons screened rather than settled sewage is aerated, and there is no sludge return (see figures 6-9). Retention times for domestic sewage are typically 2–6 days and lagoon depths are 2–4 meters. The effluent from the lagoon contains 200–500 milligrams per liter of suspended solids (activated sludge flocs) and therefore requires further treatment either in an ordinary secondary sedimentation tank (retention time: 2 hours, minimum) or in a settling pond (retention time: 5–10 days). The latter is more

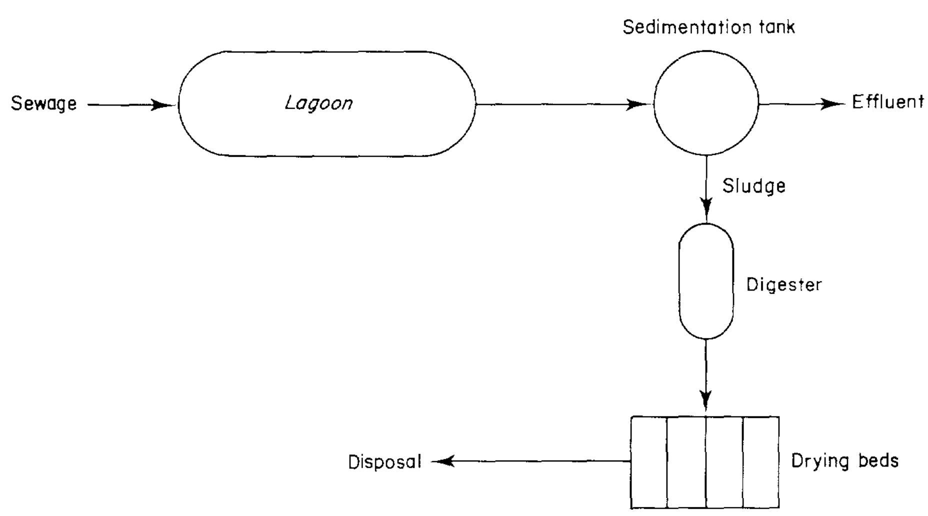


Figure 6-9. *Flow diagram for an aerated lagoon incorporating sludge digestion.* From Mara (1976)

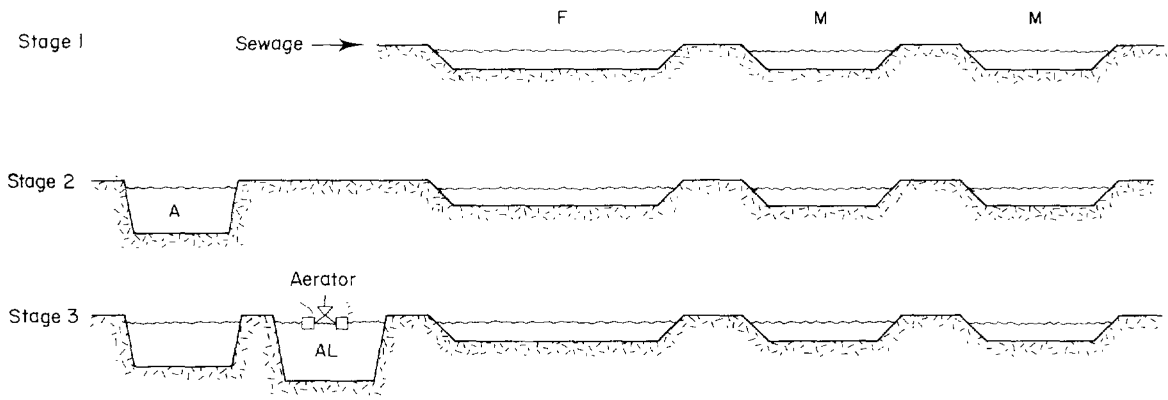


Figure 6-10. *Stages in development of a waste stabilization pond–aerated lagoon system.* F. Facultative pond; M maturation pond; A anaerobic pond; AL aerated lagoon. At stage 3 additional maturation ponds will probably be necessary. In some cases septic tanks may replace anaerobic lagoons (usually for populations below 10,000)

advantageous because it is often cheaper, easier to maintain, and more efficient in terms of removal of excreted pathogens. Aerated lagoons are often used to extend the capacity of existing waste stabilization pond systems (see figure 6-10).

Pathogen survival

In the aerated lagoon itself there will be incomplete removal of excreted pathogens, although as a result of the longer retention times the removal achieved is better than that obtained in the conventional activated sludge process. In the settling pond there will be complete removal of excreted protozoa and helminth eggs, but schistosome and hookworm larvae may appear in the effluent, which will also contain pathogenic bacteria and viruses. The effluent may, however, be treated in one or more maturation ponds to achieve any desired level of pathogen survival.

Oxidation Ditches

In addition to the aerated lagoon, the oxidation ditch is another modification of the activated sludge process.

Technical description

Screened sewage is aerated in, and circulated around, a continuous oval ditch by one or more special aerators (called "rotors") placed across the ditch (see figure 6-11). The ditch effluent is settled in a conventional secondary sedimentation tank, and

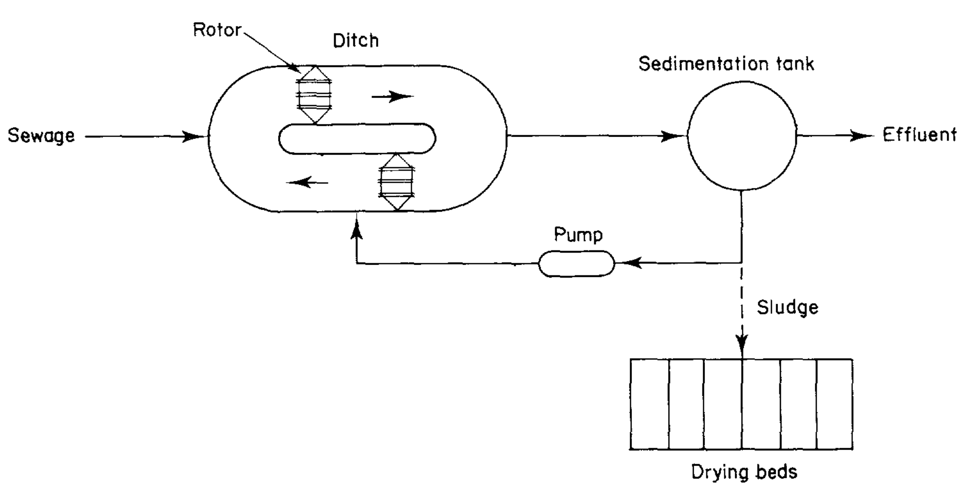


Figure 6-11. *Flow diagram for an oxidation ditch.* From Mara (1976)

almost all the sludge (>95 percent) is returned to the ditch. The small quantity of excess sludge is placed directly on sludge drying beds. The hydraulic retention times are 1–3 days in the ditch and 2 hours, minimum, in the sedimentation tank. Because a high proportion of the sludge is recycled, the mean retention time for solids is 20–30 days; as a result there is only a small production of excess sludge, which is highly mineralized and requires only dewatering on drying beds. The main engineering advantages of the process are that primary sedimentation is eliminated and that sludge production and treatment are minimal.

Pathogen survival

The effluent from the sedimentation tank has a pathogen content similar to that of the effluent produced by a conventional activated sludge process, although as a result of the increased retention time slightly lower survivals are achieved. The small quantity of sludge produced is similar in quality to that produced by an anaerobic digester and contains the same range of excreted pathogens.

Tertiary Treatment

Tertiary treatment methods are increasingly used in Europe and North America to improve the quality of effluent produced by conventional treatment works. Sophisticated systems designed to reclaim effluent for potable water, such as the one used at Windhoek, Namibia (Stander and Clayton 1977), are not intended by the term, but rather those treatment processes used to upgrade the physicochemical quality of an effluent prior to discharge. Tertiary treatment processes originally were not designed primarily for pathogen removal, but some of them do have good pathogen removal characteristics.[9]

Rapid sand filtration

This is perhaps the most common tertiary treatment found in larger treatment works. High loading rates (200 cubic meters per square meter daily) and frequent backwashing (1–2 days) prevent the build up of much biological activity in the filter. Some viruses will be adsorbed to solids and some bacteria retained. Protozoal cysts and helminth eggs may be retained because of their size. In short, the pathogen content of the effluent may be reduced but not substantially, and probably insufficiently to justify investment in this filtration method by the health benefits it yields.

Slow sand filtration

This method may be used in small treatment works. The low loading rates of the filters (2–5 cubic meters per square meter daily) causes them to occupy a large land area. Substantial biological activity builds up, especially in the upper layers of the filter, and pathogen removal may be very high. Removal of 4 $\log_{10}$ units of excreted viruses and bacteria may be expected from a well-run unit, with virus removal a little higher than bacteria removal. Complete retention of protozoal cysts and helminth eggs has been recorded. Slow sand filters are therefore highly effective in removing pathogens from a secondary effluent, but their land requirement makes them suitable only for small treatment works.

Land treatment

Secondary effluents may be applied to land in three ways; application to land for deep percolation and groundwater recharge, application to land for collection in underdrains, and application to sloping grass plots for collection in downslope channels. The first two systems can have extremely high pathogen removal performances,[10] whereas the grass plot system is less effective because some of the effluent runs over the surface of the soil, rather than through it. There is little or no information about the application of these processes in the tropics or in developing countries. If poorly managed, they will probably lead to the creation of a foul and unsanitary bog. In addition, all land application systems pose the potential threat of groundwater contamination.[11]

Maturation lagoons

Conventional effluents can be upgraded in maturation lagoons. The principles involved are exactly as described for waste stabilization ponds (see the section of that title, below, and figure 6-10). If two or more maturation ponds are used, with perhaps 5 days of retention in each, total removal of protozoal cysts and helminth eggs will be achieved. High levels of virus and

9. The effect of tertiary processes in removing excreted pathogens from secondary effluents is reviewed in Part Two.

10. See chapters 9 and 13 and Uiga and Crites (1980).

11. See chapter 7, the section "Effluent Discharge. To groundwater."

bacteria removal are also effected, and a pathogen-free effluent may be produced by adding sufficient ponds.

Other tertiary treatment processes

Several other tertiary treatment processes are in use or under experimentation, including coagulation, carbon adsorption, irradiation, and ozonation. The effects of these on enteroviruses and fecal indicator bacteria are reviewed in chapters 9 and 13. These processes are, in general, too technically complex and costly to be appropriate for sewage treatment in developing countries.

Effluent Chlorination

The chlorination of sewage effluents is commonplace in only a few countries (notably the USA, Canada, and Israel). Its purpose is to reduce the pathogen content of conventional effluents. As discussed earlier, it represents the borrowing from the water treatment industry of a technology that might overcome the poor pathogen removal characteristics of conventional treatment systems.[12] Effluent chlorination has a number of serious limitations, the principal one being that in some senses it does not work. At best, chlorination is complex and difficult to control. Chambers (1971) writes that

> 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 these reasons it should be rejected except where the highest levels of management and process control are guaranteed.

Chlorine has to be applied in heavy doses (10–30 milligrams per liter) to achieve coliform concentrations of less than 100 per 100 milliliters of effluent. These levels of chlorine will also kill pathogenic bacteria if the chlorine demand of the effluent is not too high, if the chlorine and the effluent are well mixed, and if adequate contact time (at least 1 hour) is allowed. But regrowth of coliforms and *Escherichia coli* following chlorination has been widely reported (for instance, Shuval 1977), and the regrowth of pathogenic bacteria has not been fully ruled out. Moreover, all bacteria in the effluent are affected by the chlorine, many of which are essential for the effluent's natural self-purification. If the effluent is discharged into a river or lake, the chlorine may adversely affect the ecology of the receiving water and hinder its natural oxidation processes. Further, the chlorine will be present in such forms as chlorinated organic compounds, which are less biodegradable than their parent compounds and are directly toxic to fish and other aquatic life (Water Research Centre 1979).

Excreted viruses are more resistant to chlorination than bacteria.[13] Chlorine doses of 30 milligrams per liter and above have been recommended; even so, complete viral removal may not be achieved (Melnick, Gerba, and Wallis 1978). It appears, at least from South African experience (Nupen, Bateman and McKenny 1974), that chlorination beyond the breakpoint—with resultant free, residual chlorine as HOCl—may be necessary to effect viral removal. Depending on the chlorine demand and pH of the effluent, breakpoint chlorination may require high doses and will always require efficient and vigilant process control.

It is most unlikely that chlorination of effluents will be effective in eliminating protozoal cysts because they are more resistant than either excreted viruses or bacteria. Most helminth eggs will be totally unharmed by effluent chlorination.

It is evident from these shortcomings that effluent chlorination may not be particularly effective in removing pathogens from conventional effluents. That chlorination may have deleterious environmental consequences—including the proliferation in water supplies of carcinogenic chlorinated hydrocarbons, which are formed by the reaction of chlorine with organic material—must also be considered (Buxton and Ross 1979; Carlo and Mettlin 1980; Deinzer, Schaumburg, and Klein 1978; Grabow 1979; Hais and Venosa 1978; Wilkins, Reiches, and Krusé 1979). Nupen and Morgan (1978) write, regarding effluent chlorination below the breakpoint in South Africa, that

> Present findings indicate that the practice not only fails to provide an effective barrier to the spread of diseases but ignores the environmental impact on receiving waters ... Under no conditions can this type of chlorination be considered as a substitute for the adequate treatment of wastes.

12. See chapter 4, the section "Objectives of Night Soil and Sewage Treatment."

13. Inactivation of enteroviruses and fecal indicator bacteria by effluent chlorination is reviewed in chapters 9 and 13.

Waste Stabilization Ponds

Waste stabilization ponds are the most economic method of sewage treatment wherever land is available at relatively low cost (Muiga and Reid 1979). Thus, they are widely used in North America. But their principal advantage in warm climates is that they achieve low survival rates of excreted pathogens at a much lower cost than any other form of treatment, with maintenance requirements simpler by several orders of magnitude. In fact, a pond system can be designed to ensure, with a high degree of confidence, the total elimination of all excreted pathogens. This is not usually achieved in practice because the incremental benefits resulting from achieving zero survival, rather than low survival, are less than the associated incremental costs. Yet waste stabilization ponds are the best form of treatment in tropical, developing countries because they can achieve any level of pathogen removal desired. From a strictly health-directed viewpoint, the fact that ponds can do this at lowest comparable cost is an additional advantage.

Technical description

Waste stabilization ponds are large, shallow ponds in which organic wastes are decomposed by micro-organisms in a combination of natural processes involving both bacteria and algae. The waste fed into a stabilization pond system can be raw sewage, aquaprivy effluent, or diluted night soil (figure 6-10). There are three kinds of ponds in common use:

- Anaerobic pretreatment ponds, which function similarly to open septic tanks; they have retention times of 1–5 days and depths of 2–4 meters.
- Facultative ponds, in which the oxygen necessary for biooxidation of the organic material is supplied principally by photosynthetic algae, which grow naturally and with great profusion in them; they have retention times of 10–40 days and depths of 1–1.5 meters.
- Maturation ponds, which receive facultative pond effluent and are responsible for the quality of the final effluent; they have retention times of 5–10 days and depths of 1–1.5 meters.

Anaerobic and facultative ponds are essentially designed for biochemical oxygen demand (BOD) removal, whereas the function of maturation ponds is the destruction or removal of excreted pathogens. These three ponds are complementary and should normally be used in conjunction with one another to form a series. Although it is all too common to find only a single facultative pond treating domestic wastes, this represents a false economy when health is considered. Maturation ponds are necessary to ensure low pathogen survivals. Good designs (see figure 6-10) incorporate a facultative pond and two or more maturation ponds; for strong wastes (biochemical oxygen demand of >400 milligrams per liter), the use of anaerobic ponds as pretreatment units ahead of facultative ponds is often advantageous because they minimize the land requirements of the whole pond system.

Pathogen survival

Several authors have reported the fate of fecal indicator bacteria in ponds (see chapter 13).[14] High removal rates of 99.99 percent or better have been reported for series of three, four, or more ponds. Complete elimination of *Salmonella* and other enteropathogenic bacteria can be achieved in pond systems with long retention times (30–40 days), particularly if ambient temperatures are above 25°C (see chapters 13 and 15). It is known from both theoretical considerations and field experience that a series of ponds will perform far better in removing BOD and excreted bacteria than will a single pond with the same overall retention time. A series of five to seven ponds, each with a retention time of 5 days, can produce an effluent containing 100 fecal coliforms and fecal streptococci per 100 milliliters. Such an effluent can be safely used for unrestricted irrigation.

Little is known at present about the fate of viruses in ponds in warm climates or developing countries (see chapter 9). Viruses adsorb to solid particles that may settle to the sludge layer, and other biological and physical factors may be specifically virucidal; for instance an increase in pH to $\geqslant 9$ caused by blooms of algae. Irrespective of such effects, inactivation of excreted viruses will proceed rapidly in warm waters, and may be 1–2 log units per 5 days in ponds at >25°C. A pond system with an overall retention of 30 days in a warm climate should therefore achieve a reduction of excreted viruses of not less than 6 log units (99.9999 percent).

Reports on the effect of ponds on protozoal cysts and helminth eggs (see chapters 20 and 23) indicate 100 percent removal in all cases in which well-designed, multicelled ponds with a total retention time of >20

14. A compilation of original sources and findings on pathogens in waste stabilization ponds is given in Part Two, especially chapters 9, 13, 20, and 23.

days were investigated. Hookworm larvae may survive for up to 16 days in aerobic ponds. Because of this fact, hookworm larvae have been reported in the effluent from ponds with an overall retention time of < 10 days; they have not, however, been reported in the effluent of ponds with retention times of > 20 days. The majority of schistosome eggs in an aerobic pond will settle; in a facultative pond they will either settle or hatch into miracidia. Miracidia will either die or infect an intermediate snail host if the correct snail species is colonizing the pond (as may be the case in badly maintained and vegetated ponds). Even if cercariae emerge, they should not find a human host to invade and will die within 48 hours.

An important consideration in the design and operation of waste stabilization ponds is that they may become sites for mosquito breeding. The most common mosquitoes found breeding in ponds belong to the *Culex pipiens* complex, which favors polluted water. The distance between the town producing the sewage and the pond system treating it is usually well within the flight range of the mosquitoes, which may be as great as 10 kilometers. Any large outbreak of mosquitoes will thus be a nuisance (depending on the weather conditions at the time). Moreover, because the mosquitoes can serve as vectors for disease, it is essential to attempt to keep waste stabilization ponds free of mosquitoes. Studies on mosquitoes in ponds (reviewed in chapter 36) indicate that emerging and encroaching vegetation are important in encouraging breeding. It is easy in practice to discourage vegetation growth in ponds by making the ponds > 1 meter deep and using concrete slabs, rip-rap, or soil cement on the embankments at the surface water level. Reinforcing the pond's banks not only prevents vegetation from growing down the embankment but also halts erosion of the embankment by wave action. Any residual vegetation problem may be dealt with by the well-supervised staff of laborers who should be employed on all waste stabilization pond plants. Mosquito breeding in ponds can thus be largely circumvented by good design and good maintenance.

In summary, well-designed pond systems—incorporating a minimum of three cells, and having a minimum total retention time of 20 days (see figure 6-12)—produce an effluent that will contain only small concentrations of excreted bacteria and viruses. Excreted helminth eggs and protozoal cysts will be completely eliminated. Bacterial or viral pollution can be further reduced (or eliminated) by adding more ponds to the system. The effluent is suitable for direct reuse or discharge into receiving waters.

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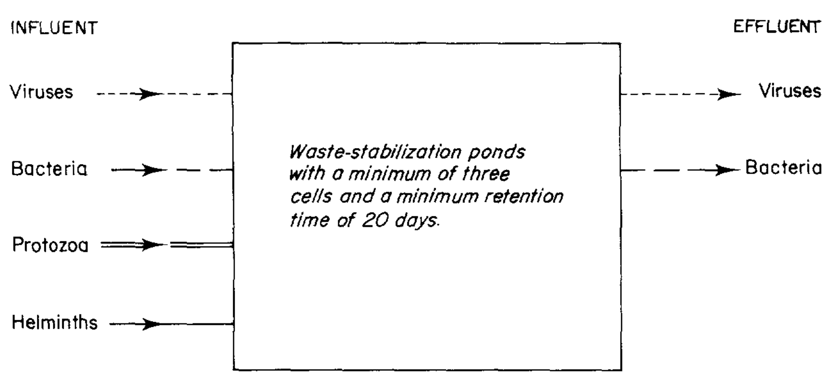

Figure 6-12. *Pathogen flow through a waste stabilization pond system*

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